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ABSTRACT

Proceedings from a June 1984 sympoisum on special education technology are presented in this document. A background paper on "Technology Trends in Special Education" (C. Blaschke) deals with microcomputer use, telecommunicaton systems, videodiscs communication aids and adaptive devices, and makes projections for instructional and administrative applications. A synopsis of the symposium presentations addresses five topics: evaluation of computer assisted instruction and computer managed instruction, use of existing technology in applied research settings, design and measurement issues related to CAI evaluation in special education, long-term potential applications and advanced technologies in special education, and research in other federal agencies. Five conference papers are then presented: "Issues and Problems in Devising a Research Agenda for Special Education and Technology" (G. Bracey); "Macro Research on Technology: Micro-Research on Education" (F. Roberts); "Expert Systems: Their Potential Roles within Education" (M. Colbourn); and "Robots and Special Education: The Robot as Extention of Self" (D. K. Kimbler). (CL)

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PROCEEDINGS

FIRST SPECIAL EDUCATION TECHNOLOGY RESEARCH AND DEVELOPMENT SYMPOSIUM

June, 1984

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PREFACE

One of the fastest growing areas in the education research community is the investigation of how computer technology can be used to enhance the education of handicapped students. Identified as a priority area for funding, the Department of Education, Office of Special Education Programs (ED/SEP) in 1983-84 allocated over $8 million for technology related activities.

In establishing this priority area, a need was identified by ED/SEP to clarify the state-of-the-art of R & D efforts on a national basis. The first R & D Symposium, held in June, 1984 in Washington, D.C. was based on the premise that performers of research and development might share information concerning their activities and facilitate collaborative projects and avoid unnecessary duplication of efforts.

The two-day symposium was attended by educators, developers of software, commercial and noncommercial distributors, and government officials representing five federal agencies. The purpose of the symposium was to improve the dialogue among federal funding agencies and leaders in the field working to enhance the development of programs and products designed to improve the quality of instruction to handicapped children.

Topics for the agenda were selected following a review of the literature on applications of technology. In addition, active R & D professionals reacted to a proposed list of topics, and identified possible presenters to prepare papers and for presentation at the symposium.

This Proceedings Document is intended to capture the essence of that symposium. It contains a background paper on technology trends in special education, a synopsis of all presentations, and five papers presented during the symposium:

- "Technology Trends in Special Education", by Charles Blaschke, describes trends in computer technology applications in special education. Technologies addressed are microcomputerized videodiscs, telecommunication systems, and communication aids and adaptive devices, identifies current issues, and makes projections regarding both instructional and administrative applications.

- "Synopsis of Presentations" provides an overview account of the symposium, summarizing the presentations, and identifying key issues which emerged throughout the two days.

- "Issues and Problems in Devising a Research Agenda for Special Education and Technology", by Gerald Bracey, highlights difficulties associated with the accurate measurement of constructs associated with learning. He says the current practice of developing technology related materials while we still know very little of how people learn places a great burden on educators, researchers and developers. He also provides a timely criticisem of: 1) the manner in which research is conducted; and 2) the practice of forming policy in athe absence of adequate research data.

- "Macro-Research on Technology; Micro-Research on Education", by Tom Hanley, provides a critical review of CAI effectiveness literature. He argues that research on CAI has placed the focus on the technology itself, rather than on the process of learning. By identifying a paradigm for future research, Hanley proposes a solution to the difficulties associated with performing and interpreting CAI and CMI effectiveness research.

- "An Overview of Intelligent CAI Systems", by Franklin C. Roberts, provides an overview of artificial intelligence (AI) including the principles of AI and the components of a fully developed AI System. Roberts also provides a review of the developments occurring in intelligent computer-aided instruction (ICAI), as well as the benefits and limitations of ICAI.

- "Expert Systems: Their Potential Roles Within Education", by Marlene Jones Colbourn explains the general concepts underlying the development of expert systems, and describes the various applications of such systems for teaching, tutoring and educational diagnosis. Colbourn advocates the use of expert systems for diagnosis and assessment of children suspected of having learning disabilities.

- "Robots and Special Education: The Robot as Extension of Self", by Del Kimbler, an industrial engineer who specializes in the design of robotic systems, addresses 1) use of robots as an aid to certain handicapped populations; 2) the requirements for robot performance; and 3) the research agenda necessary for the use of robots in special education in the future.

TECHNOLOGY TRENDS IN SPECIAL EDUCATION

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Electronic learning technology has become a reality in public education. The dramatic growth in the use of microprocessor-based systems, telecommunications, and related technologies in education can be attributed to: (a) rapidly decreasing costs of hardware relative to speed and capacity; (b) pressures from parents as microcomputer home use has increased even greater; (c) grassroots initiatives from "computer buffs" within schools; (d) availability of Federal and some state funds through "block" grants; (e) Federal deregulation, particularly in the telecommunications area; and (f) political pressures from governors and legislatures upon SEAs, of which virtually all now have policies on education technology. The use of electronic learning technology in special education has increased even more dramatically due to the above factors and additional ones. The purpose of this paper is to describe current and future trends related to the potential use of microcomputers, videodiscs, telecommunications systems, and communication aids and devices for special education generally. Other speakers on this panel will focus on specific technology applications and their current and projected use in providing services to the deaf.

Since 1981, Education TURNKEY Systems has collected and compiled data bases and trend information related to user needs, technology advances, and relevant applied research and development. Through Project SpEd Tech, TURNKEY developed three-year scenarios on various technology applications in special education, based upon interviews with over 200 publishers and developers of software products. In Project Tech Mark, we conducted an extensive market research analysis which was provided to publishers and developers to encourage their development of products specifically designed for special education populations. Through Project SLATE, which is designed to assist state-level policy makers (including legislators and governors) to develop plans for the effective use of technology, TURNKEY staff have been able to monitor changing user needs and the evolution of state policies. And most recently, through the SpEd Tech Center Project, conducted by NASDSE, TURNKEY conducted a needs assessment survey related to technology use of all state directors of special education and planned the first annual R&D Symposium on special education technology. Many of the current trends and projections presented below are based upon one or more of the above projects and/or studies.

Why Technology In Special Education?

The significant growth and use of electronic learning technology, particularly microcomputers and communication aids, in special education which has occurred over the last few years can be attributed to a number of factors.

First, the passage of P.L. 94-142 and mirror image state laws have generated a demand for technology use in both instruction and administration. One of the findings from our Study of the Impact of P.L. 94-142 Upon LEAs, conducted in the late 70s, found that a typical teacher spent over ten hours per year per child developing and updating IEPs. Recent evaluations in Wayne-Westland, Michigan and elsewhere have reported the use of administrative packages on low-cost microcomputers can reduce the time per pupil to about an hour to develop an IEP and ten minutes to update it. In addition, many LEAs have found that the microcomputer can reduce routinized staff time and paperwork associated with assuring other procedural safeguards noted in Exhibit 1. By requiring an IEP for every child, including those in mainstream settings, the law generated a demand for instructional management systems which could monitor individual progress of students at varying levels and proceeding at different learning rates. In many instances, the use of computer assisted instruction, particularly as supplemental and enrichment activities and as reinforcement mechanisms, can further enhance the individualization process.

Second, the monies allocated to special education have increased dramatically over the last decade. For example, in 1976 approximately $4.6 billion was allocated to special education by Federal, state and local education agencies. In 1983, the total funding increased to over $12 billion with a projected increase by 1985 to approximately $15 billion. Once considered a "thin market" by publishers, the courseware and software developers and electronic publishing firms have been more responsive to special education than education generally, especially over the last year or so. In addition, trade associations, such as the National Audio Visual Association, have projected a higher rate of increase in per pupul expenditures in special education for instructional equipment and materials than in education generally, from $367 million (1982) to $650 million in 1985. This has provided further inducement for the private sector to attempt to penetrate and/or expand its market share in special education.

Third, related to the above, the cost of providing services to handicapped students is significantly higher than those associated with services for nonhandicapped children. In Exhibit 2 we display the comparison based upon a study conducted by the Rand Corporation, 1980. In the area of administrative processing and overhead, the costs associated with handicapped students are approximately $500 per year compared to $200 per year per nonhandicapped child. These administrative processing costs, combined with an additional $200 to $300 related to IEP development, suggest that a software package cost of $2,000 could pay for itself for as few as 20 students if staff time and paperwork could be reduced by as little as 25%.

Fourth, as parents of handicapped children become increasingly aware of the potential use of communication aids and devices interfaced with commercially available microcomputers, they too are bringing pressures upon LEAs and SEAs to make these systems available for the handicapped child in school and/or in the home environment.

And last, a number of SEP-funded projects have also provided funds and other incentives for expanded use of technology in special education

Microcomputer Use and Trends

By December 1983, approximately 350,000 microcomputers (general purpose microcomputer vs. single dedicated hardware/software systems) were in the public schools. Approximately 60,000 were used primarily for special education; of these, 15,000 were used for administrative purposes, while 45,000 were for instructional purposes. Joint use was identified in approximately 20% of the LEAs. By 1985-86, approximately 500,000 microcomputers will be in the public schools with approximately 150,000 used primarily for special education. Approximately 30,000 will be used for administrative purposes.

- Instructional Applications and Needs

  The National Needs Assessment Study, conducted by ETS (1980), identified a number of "perceived needs" (on the part of special education teachers and administrators) in reading, word attack skills, math, and social-behavior content areas. The study also identified a demand for computer assisted instruction (e.g., for every one teacher with a child receiving CAI instruction in 1978, five additional teachers felt that CAI was the most appropriate delivery system for instruction in high priority curriculum areas). The CEC conference responses reflect significant changes in priority courseware curriculum/content areas. For example, while 48% of the attendees felt reading and other language arts courseware was still their highest priority need, only 4% felt that math courseware was a priority need. Evidently, the large number of math courseware packages is meeting priority special education needs, with and without adaptation. On the other hand, approximately 20% of the CEC conference attendees felt a priority need for computer literacy courseware This need is slightly less than the general demand for computer literacy via CAI as reported by Anderson's 1982 survey, which found that 35% of teachers which had access to at least one microcomputer felt that CAI was the most appropriate delivery of computer literacy curriculum.

Over the last year, special education administrators, particularly in urban districts, have expressed an increasing need for tutorial-type programs used for introducing concepts, although problem-solving and drill-and-practice still constitute approximately 60% of the top priority instructional courseware needs. In 1983, however, three firms (DLM, Random House, and Hartley Courseware) released over 100 programs which allow special education teachers to adapt or adjust the courseware for special education students. Adjustable simulation programs will emerge within one year.

o Priority Needs for Administrative Applications Changing

The CASE survey, conducted in the Fall of 1982, found that the overwhelming number of administrative packages which were commercially purchased (68%) or developed internally (80%) were of a single-purpose nature. Priority single-purpose applications included: student enrollment (94%); student tracking (45%); student program to monitor student's education programs (40%); budget monitoring and reporting (23%); personnel (22%); word processing (22%); and assessment (12%). Only about 30% of the administrators using computers in special education used multipurpose programs. While approximately 80% of the CASE respondents used microcomputers, approximately 43% used combinations of microcomputers, mainframes, and minis. While about 50% of the CEC attendees identified CAI as a priority-type of software need, approximately 15% felt a priority need for direct support by teachers such as CMI, diagnosis and prescription; 20% for administrative support such as student records, IEP printing, and tracking; and 3% for test scoring and analysis.

In addition, 45% of the CEC attendees stated that their district plans call for increased use of microcomputer technology in both special education administration and instruction. Most recognized the need for multipurpose programs. This perceived need is consistent with SpEd Tech findings from a year ago and from discussions with a number of special education administrators. Moreover, multipurpose applications are more likely to be purchased than developed internally. Approximately 50 commercially available multipurpose packages were available in 1984 and are being used in special education administration. Interestingly, about 50% of the participants in SpEd Tech workshops felt that the need for microcomputer administrative applications would still be high, even if state or Federal requirements mandated in P.L. 94-142 were to be significantly reduced.

Within the next three to six months, at least one client customizing multipurpose administrative package will be available for individual LEAs and schools and for SEA/LEA networks. Under a Small Business Innovation Research program contract, we are presently field-testing a client customizing version of the Modularized Student Management System which we previously have customized ourselves for use by LEAs and SEAs across the country. If the field-test results of the client customizing concept are successful, we anticipate that costs will be reduced by as much as 50%. In addition to client customizing packages, a number of states are using data base management programs to develop both single-and multipurpose administrative applications. We anticipate these systems to be increasingly used along with program generators. In addition, in the next two years we anticipate the emergence of several instructional management packages, which will be built upon artificial intelligence research and development transferred from the defense and other areas to act as an expert systems "tool" for managing the education process for special education populations. Several groups in Tennessee, California, Michigan and Canada are developing various types of expert systems for use in the schools.

- Special Education Courseware Distribution Differs Significantly from Regular Education

A TALMIS report (1983) found that approximately 41% of all courseware purchased by schools was purchased from retail outlets such as Computerland, Radio Shack retail outlets, etc. Only 13% was purchased from traditional audiovisual dealers and school suppliers. Attendees at the CEC conference indicated approximately 30% of their courseware was purchased from education dealers or sales representatives, while only 17% was purchased from commercial retail outlets. Approximately 19% was purchased directly from publishers through catalogues, etc. In addition to a heavier reliance upon education dealers and sales "reps," special education consumers purchased a surprisingly large amount of software through direct mail or catalogues, even though SpEd Tech respondents indicated that mail was the "least preferred marketing strategy" to help them make special education courseware decisions. Electronic distribution of courseware through state-operated and/or subscription services is now a reality and can be expected to spread over the next year or two. This technology, along with alleged copying by schools, will drive even more courseware publishers to the home market or out of business.

- In-House Software Development a Mixed Bag

While SpEd Tech respondents felt that they would be more likely to develop in-house administrative, single-purpose applications than instructional courseware, CEC attendees indicated that approximately 40% of noncommercial software which they use was developed in-house; only 8%, mostly administrative, was developed by outside groups. Surprisingly, less than 5% of noncommercial software was obtained from other LEAs or intermediate units. On the other hand, approximately 25% of the CEC respondents felt a great priority need for assistance in adapting or modifying software for special education students, which has implications for courseware developers/publishers. Publishers interested in the special education market should reconsider restrictive copyright policies to allow LEAs to adapt courseware.

- Other Changing Needs

Priority information needs identified by CEC attendees (March 1983) indicate that "computer literacy/orientation" is still a major need (50%); however, reflecting a degree of maturation on the part of special education administrators and teachers, the demand for comparative information on specific applications is increasing (28%), while the need for comparative information on hardware has dropped to less than 1%. Interestingly, priority needs for comparative information on adaptive devices have increased significantly between 1982 and 1983 with approximately 13% of the CEC attendees having indicated that as a high priority information need.

While assistance in selecting appropriate software remains the highest technical assistance need for districts, a surprising number of CEC attendees reported a priority need for assistance in systematic planning for the use of technology in special education (31%). This is interesting in light of the fact that 75% of the Hartford attendees had one or more microcomputers presently being used in special education. Evidently, districts first experiment with micros in special education and then recognize a need for systematic planning, particularly in light of tighter budgets and reductions in Federal funds.

Telecommunication Trends

Experimental use of telecommunications systems has not been uncommon in the deaf community, with such experimental efforts as Deafnet, Baudot compatible TDY systems, and other networks, operated by groups such as Gallaudet College. In special education generally, telecommunications has been limited to electronic mail and bulletin board systems, using networks such as SpecialNet, which is a subsystem of GTE Telenet. SpecialNet is the largest education electronic mail/bulletin board system in the country, with over 2,000 SEA and LEA subscribers in December 1983. In addition, both LEAs and particularly parents of handicapped students are increasingly using other telecommunications networks such as CompuServe, which is particularly popular in the Midwest especially among farmers and agriculture extension agencies. In addition, two SEP-funded projects will establish information exchanges on software and on technology applications generally, particularly with a focus upon SEAs, LEAs, and parents of handicapped students.

The recent advances in telecommunications systems and networks can be attributed to a number of factors. First, the amount of deregulation by the FCC and other Federal regulatory agencies over the last two years has had a greater impact than that over the previous 20 years, providing new opportunities for commercial use. In some instances, this deregulation has been at the expense of education and the special education community. For example, in April 1983, the FCC deregulated the use of the FM subcarrier to allow for commercial use that previously had been dedicated to other services for the handiapped. Subsequent deregulation of ITFS stations for commerical use has the potential of removing such capabilities from state education agencies which have failed to use dedicated channel capacity. Second, the "terminal-end" equipment base has increased dramatically as microcomputers have invaded the school and home. This equipment base, combined with new advances in low-cost modems and other related peripherals, provides a unique opportunity for increasing subscriber bases and, hence, investment in development of data bases and programs. Third, significant advances have occurred in the use of voice and data transmission technology, including fibreoptics. And last, standards are beginning to emerge in such areas as videotext as giants of the communication industry, such as CBS, AT&T and others, have created joint ventures. The establishment of standards in this area will significantly increase videotext use throughout the country at the expense of many telecommunication firms which "bet" on other standards.

Over the next two or three years, a number of significant trends in terms of the use of telecommunications will occur in education, including electronic distribution of software and courseware.

A survey which was conducted in 1983 found that one of the highest priorities among the state directors of special education was the creation of SEA/LEA networks and telecommunications systems. Most of these networks now consist of microcomputers at the LEA level, tied into larger "mega micros," mini, or mainframe computers at the state level. LEAs can use the systems for developing and upgrading IEPs. SEAs use them for desk audits, monitoring, and reporting purposes. Such systems are operational in Louisiana, Alaska, and can be expected in other states, such as West Virginia which now has a microcomputer-based network designed for use in vocational education.

While on-line distribution networks, such as that in West Virginia, can be expected to be used for reporting purposes, a number of other states are seriously exploring the possibility of newer, lower cost broadcast systems for both electronic mail and courseware distribution. For example, New York State is planning to use the recently deregulated FM subcarrier or vertical blanking space (videotext) for broadcast of electronic mail software evaluations, and actually distributing courseware to local school systems. One such network is represented by INC, a joint venture of National Public Radio and National Information Utilities. Pilot demonstrations of the INC system are planned for Maryland, Virginia, and several other states over the next year. While the costs of such a system are significantly lower than existing telecommunications systems such as The SOURCE, CompuServe and SpecialNet, the technology still remains somewhat dirty, requiring several broadcasts of courseware for example. In its present configuration, the INC system could distribute courseware to "information utilities" located at the school district or community level, which would be accessible to parents or individual students at learning stations with low-cost, semi-smart terminals costing less than $100.

As telecommunication systems using broadcast FM, videotext, or even on-line distributive networks emerge in communities, the opportunities for increased and improved relationships between parents and LEA staffs will be increased. Several California communities are experimenting with such systems, allowing parents to tap into the records of their students and for LEA staff to provide messages via electronic mail to parents. Opportunities for more efficient involvement of parents in procedural safeguards such as developing and updating IEPs, parent conferences, etc. will be enhanced. In addition, opportunities for parents to coordinate homework and supplemental instruction at home could be increased significantly, as one of the major information requests on the part of parents of handicapped kids has related to the selection of appropriate courseware and adaptive devices for their use in the home.

Videodiscs

Most of the Department of Education funded research and development of videodisc technology in education has focused on handicapped populations. The pioneering work of Utah State University through Hofmeister and Thorkildsen and the University of Nebraska (Nuegent) illustrate the point. However, over the last four years, use by LEAs can be characterized as a "chicken and egg game." On one hand, LEAs have been hesitant to purchase videodisc equipment because of the lack of educational programs. On the other hand, software developers and production units have not been producing programs because of the inadequate equipment base in the schools. During the last six months, the situation has changed rather dramatically. The current issue of Electronic Learning is devoted to videodisc systems for education.

First, LEA purchases of videodisc equipment increased rather dramatically from approximately two percent of the districts in June 1982 to approximately 20 percent in September 1983 having one or more videodiscs. Approximately 70 percent of the large urban districts plan to have videodisc units in use by the end of 1984.

Second, while most educators within LEAs and developer firms have been betting on the laser optical disc, major breakthroughs occurred in the freeze-frame capability and random access speed of the capacitance disc.

Third, as the use of videodisc technology increased dramatically in industry training, point of sales, and in military training, production has increased dramatically and costs have dropped rather dramatically over the last year.

And fourth, largely as a result of the above trends, a number of large firms are investing in videodisc program development and production designed for education use. For example, under a two-digit million dollar contract, Utah State is designing 70 one-hour videodisc programs on math, science, and technology in education. Firms such as SVE and MicroEd have joined forces to produce and market programs which can be tied into the new interface devices prevalent in home computers such as Commodore. Other electronic learning publishers, such as Grolier, are expanding their videodisc program lines. At this time, software developers which have produced and marketed courseware on floppy discs (which are difficult to protect) are converting to videodisc formats which, of course, offer significant protection against illegal copying and pirating due to the high cost of videodisc program reproduction. Videodisc program sales are expected to approach $600 million by 1987-1988. Industry sources project that approximately 20 to 30 percent of these sales will be directly to LEAs or the home education market.

Communication Aids and Devices

By 1981, two courseware firms had developed courseware packages which could be interfaced with communication devices such as voice synthesizers or voice input devices. Today, approximately 75 percent of the producers and publishers of the software which is designed for or could be used in special education provide opportunities for at least one of their packages to be interfaced with one or more adaptive devices. The primary factors contributing to the increased availability of courseware interfaced with adaptive devices can be attributed to several factors. First, the cost of these devices has dropped significantly over the last two years as production of these devices and interface cards has increased dramatically, since they are used by handicapped persons in the workplace and/or for general entertainment in the home. For example, the ShadowVet, produced by Scott Instruments, retailed for approximately $1,000 in 1982. In 1983, the unit was selling for less than $400.

Second, major technology advances have occurred in this area. For example, Texas Instruments has developed one of the most sophisticated voice recognition and voice entry systems which can recognize up to 500 words initialized by the user. Borg-Warner Education Systems, a major producer of special education software and products recently announced the UFONICS system, a digitized voice (as opposed to a synthetic voice) which is being interfaced with existing courseware developed by firms such as MECC and others. The UFONICS system retails for less than $600.

Third, increased parent awareness of these adaptive devices could be attributed to both legitimate awareness from the Johns Hopkins First National Contest on Personal Computers for the Handicapped, as well as over-zealous advertising on the part of vendors. Independently, these parents are purchasing these devices for use at home with their handicapped children. And in combination with lawyers, a limited number of parents are attempting to pressure LEAs to purchase and use these devices, particularly in mainstreamed settings for their children, in that these children (particularly hearing and sight impaired) can access computer assisted instruction used by nonhandicapped students. These pressures may be less subtle, as lawyers threaten to sue school districts under Section 504 of the Rehabilitation Act to provide "reasonable accommodation" for handicapped students.

Over the next two or three years, increased opportunities for robotics applications, either in the educational process or as a support system for handicapped individuals, will become a reality. While the use of industrial robotics has not increased as was projected three or four years ago, technology development and engineering advances are occurring which provide for greater flexibility and eventual lower costs. For example, the "Functionoid", developed by Odetics, weighs approximately 400 pounds and can lift a three-ton truck. It can also climb stairs, step over obstacles, enter and exit automobiles, and provide other functions as a skeletal mechanism support system for immobile handicapped individuals. A number of firms presently manufacture relatively low-cost robots which can be integrated into various types of instructional settings.

Summary

Technology advances are inevitable. Technology and peripheral devices developed for business and home use will drive the nature of courseware and products available for use in education. Advances in artificial intelligence and robotics for use in industry will transfer into education over the next two to four years, contributing enormously to quality courseware which will fully use the expanding capabilities of the microcomputer. The videodisc is at the stage where the microcomputer was in education about three years ago and, indeed, will replace many of the functions of computer assisted instruction as we know it today. The quiet, unseen revolution is occurring in telecommunications which will have the most significant implications for education as we know it today. The technology is here. However, for a society so adept in developing technology, we have been inept and indeed negligent in developing the political, social, human, and organizational innovations to apply that technology in such a way that its benefits can be realized. This is particularly true in education and indeed this is our challenge.

EXHIBIT 1

P.L. 94-142/STATE LAWS

- IEP
- Procedural Safeguards
  - Assessment
  - Placement
  - Parent Involvement
- Student Monitoring
- Reporting

EXHIBIT 2

INCREASED ADMINISTRATION COST

	H/C	NON H/C
Central Admin	200	105
School Admin	209	96
Related Services Admin	87	5
	496	206

(IEP/Assessment 200 - 300)

SYNOPSIS OF PRESENTATIONS

SPECIAL EDUCATION TECHNOLOGY RESEARCH AND DEVELOPMENT SYMPOSIUM
Gallaudet College, Washington, D.C.
June 18-19, 1984

In a rare opportunity for interaction between those who perform research and development and those utilizing its products to enhance education for handicapped children, more than 50 persons participated in the Special Education Technology Research and Development Symposium at Gallaudet College in Washington, D.C. June 18-19, 1984. Included among the participiants were researchers, developers of software, commercial and noncommercial distributors, and government officials at the federal, state and local levels who formulate policies, fund R&D Projects, and direct the application of technology in special education.

During the two days, attendees heard major presentations on a broad group of topics, ranging from evaluation of computer-assisted and computer-managed instruction; the use of existing technology such as CAI, videodiscs, and adaptive devices; issues involving design and measurement; and long-term potential applications and advanced technologies, including expert systems, artificial intelligence, and robotics. They participated in both large group presentations and in small group discussions to explore these subjects in detail and to relate their individual areas of expertise to the total picture.

Demonstrations of CAI, videodisc technology, adpative devices and communication aids, and advanced technologies enabled participants to experience products resulting from current R&D projects. Key emphasis during the symposium was on the importancee of focusing on ways to achieve more effective delivery of instruction to children, and to ensure that technology enhances attributes of effective instruction rather than dictating the process.

Dr. Wendy Cullar, Director, Office of Special Education Programs, U.S. Department of Education welcomed the group and stressed that the vitality of special education programs depends on the committment to research and development. Dr. Martin Kaufman, Director, Division of Educational Services, OSEP, emphasized the importance of looking at the cumulative efforts of R&D, to see if the benefits warrant the investment and to examine the incremental advantages. He called for keeping the focus on how to teach children and how to achieve more effective delivery of instruction, and on collecting data that adds to a broader knowledge base.

The following report provides a symposis of the main presentations and the general areas of discussion.

1. EVALUATION OF CAI AND CMI: FINDINGS AND IMPLICATIONS

Gerald W. Bracey, Ph.D., Director of Research, Evaluation and Testing, Virginia Department of Education, discussed "Issues and Problems in Devising a Research Agenda for Special Education and Technology." Some of his chief points were:

° We still do not know a whole lot about how people learn. This leaves us with the burden of developing materials while our knowledge of how people learn is in a great state of flux and while the measures of effectiveness (tests) have not undergone an adequate reform to be appropriate. This means that in any research or development project the variables to be manipulated and the instruments chosen to measure the success or failure of the experiment must be chosen with extreme care.

° We have seen more collaborative problem-solving by children using computers than in the traditional classroom setting. It is too bad that an economic expediency -- we can't afford a computer for every child -- is what it took to break the typical classroom situation in which cooperation is called cheating. There is some data available that shows that even when the opportunity for cooperation is factored out of the equation, children using computers collaborate about three times as often as children using traditional curriculum materials.

° Computers seem to be especially effective in the instruction of low achieving students. No one knows why, but it is not unreasonable that the ability to set the pace, to avoid embarrassment and enjoy the unending patience of the computer has something to do with it.

° Although not a product of hard research, people who work with computers and special education students feel that they gain a sense of control over their world that is not readily available to them under either mainstreamed or contained classroom conditions.

Three issues that must be considered in R&D projects included:

1. How to evaluate outcomes? Is it appropriate to use a paper and pencil test to compare the outcome of CAI with an outcome using paper and pencils as the medium of instructions?

2. Do older studies that showed improved learning using a computer hold up in the current context in which computers are now being used and with the software that is being used? Earlier studies were usually designed as research conducted in laboratories by people who were experts in both the subject area and the machines, and they had finite duration. More recently

we have been using smaller machines with limited capacities with programs administered by untrained teachers. Given the cottage industry nature of courseware development, the use of courseware needs to be examined in light of the context of its validation versus the context in which someone else planned to use it.

3. Where the computer makes possible something not otherwise possible in a child's experience, then research on "effectiveness" is irrelevant. As cognitive psychologists provide better and more complete answers to "how do we learn?" computers will be seen more and more as useful instruments to aid learning.

In the subsequent discussion groups, participants identified some of the following points:

° An NIE study has shown the value of drill and practice, where the individual teacher has control over content. It is said teachers can create their own software but they often don't have the time or the ability to do so.

° Testing is a problem. Testing organizations resist use of computers because sequential experience on the computer does not allow the freedom to skip around to different tests items and perhaps get information from other items.

° Special education research on effectiveness of computers is difficult because of the variety of independent variables, lack of homogeneous groups of persons to test, and different kinds of interactions.

° Technology should be a tool, not a competitor. We should teach the teacher to utilize it to increase productivity.

° We can use the computer as a research tool to collect data, watching children on a daily basis to examine interaction and see how the child improves, identifying variables, then the machine can analyze the data.

2. USE OF EXISTING TECHNOLOGY IN APPLIED RESEARCH SETTINGS

Three speakers presented on three areas of applied research utilizing CAI, videodisc technology, and adpative devices.

Dr. Paul Evans of IBM described the company's "Writing to Read" project, which is teaching young children to read with a computer, using the child's own writing of a story, and building on the oral language skills that children have at age 5. Pointing out that correction is punishment, he explained that the computer shows the child how to find the right answer and encourages the joy of learning. "Children learn that it's the words that are crazy, not them. They learn to spell better than in the normal way." He also pointed to the targets of difficulty approach, in which the microcomputer can identify and remove barriers to understanding.

Ron Thorkildsen of Utah State University described the use of videodisc technology for mentally retarded students through Utah State's Interactive Videodisc for Special Education Technology project. The project has developed and field-tested instructional videodiscs including time telling, identification of coins, social skills training, and math assessment. Videodiscs are used as tools for research as well as for instructions. Material can be resequenced so that it is possible to see what happens when the sequence is changed and obtain data as you do it. Field tests can examine who is moving faster and why. Feedback thus helps tailor remediation, resulting in positive results both statisticially and educationally.

Carol Fusco-Vagnini of Prentke Romich Company explained the application of adaptive devices for severely physically handicapped nonspeaking CP children. "Minspeak", a communications device, enchances the effectiveness of communication and interaction, increasing the child's independence and improving the quality of life. It is an expressive communication system that can be reprogrammed and expanded as the child grows older. It has been incorporated into a microprocessor-based communication system, with multiple approaches (such as head control, finger, foot or hand control, or even the movement of a brow winkle). available for controlling the system. She also reviewed other areas of technology impact for physically handicapped persons, including computer access through keyboard emulators, keyguards, and switch control; environmental control, through communication aids and switch control to control appliances; and control of a powered wheelchair to enable independent movement from place to place. Prentke-Romich, under a U.S. Department of Education/Office of Special Education Programs contract, has developed the Lainey System incorporating communication, computer access and mobility into a totally integrated system.

3. DESIGN AND MEASUREMENT ISSUES RELATING TO EVALUATION OF CAI INTERVENTIONS IN SPECIAL EDUCATION

Dr. Tom V. Hanley of the Mobius Corporation, speaking on "Macro-research on Technology: Micro-research on Education," emphasized that the benefits of Computer-assisted instruction should be attributed to instructional method and novelty, rather than on the technology itself. He proposed that macro-research should investigate issues related to implementing technology in schools, while micro-research should concentrate on the process of learning. He advocated case study methods as a sensible alternative to methods using random variables or survey techniques, noting that the case study approach examines relationships among different elements in an environment and is more appropriate where there is enormous variety in applications and participants as in special education. "It is difficult to produce measures of anything in this domain that will have broad meaning, precision or replicability," he stressed. Fairly specific hypotheses can be established and tested, and a great deal of additional information can be produced that can be instructive and that can guide researchers into future promising areas of investigation. Case studies emphasise extensive interviewing, observation and documentation, and allow for the unexpected to occur while providing opportunities to obtain a wide range of potentially valuable information.

Hanly also considered the role of the special education teacher, stating that effective use of CAI converts teachers into "educational researchers," and recommending research on ways to improve teachers' knowledge of educational principles and technologies. He called for macro-research to provide an understanding of the element of CAI of CAI -- not just software but also procedures, student and teachers factors, etc. -- that contribute to appropriate and effective use of CAI. Micro-research in the classroom, he added, should include teacher knowledge and behavior to help them use technology effectively, more controlled studies of CAI that works with handicapped children, and identification of what teachers need to know to apply the principles of learning. Along with considering CAI, he added, computer-managed instruction also must be considered, because this provides the teacher with a mechanism for monitoring the student's progress and modifying the CAI.

4. LONG-TERM POTENTIAL APPLICATIONS AND ADVANCED TECHNOLOGIES IN SPECIAL EDUCATION

Three experts in advanced technology areas described the current state of R&D in these areas and their potential applications for special education.

Dr. Franklin C. Roberts, Artificial Intelligence Research, Control Data Corporation, gave an overview of Intelligent CAI Systems. He defined Artifical Intelligence (AI) as an attempt to get computers to perform tasks that if performed by a human being would require considerable intelligence to accomplish. Recent advantages have applied principles of AI in vision processing, speech understanding and generation, robotics, and expert problem-solving systems and Intelligent CAI. ICAI systems provide two-way communication between student and teacher and typically have three major components: (1) an expertise, or problem-solving model to represent the knowledge domain to be taught; (2) a tutoring or expert teaching model which manifests the instructional strategy to be used, and (3) a model of the student, including individual student characteristics and how much the student knows about the content. There are no systems as yet which have complete models for each of the components, but many of these models have been implemented at least in part.

Application areas of AI are intelligent database retrieval, natural language processing, automatic theorem proving, expert systems, automatic programming, pattern recognition, and robotics. The impact of ICAI systems on instructional delivery is not likely to be widespread in the near-term, but they offer an ideal laboratory for investigating many components in instruction and can be used as structural models for authoring systems. Other limiting factors are the amounts of development time required, costly hardware requirement, and narrow range of content domains for which systems have been built. Widespread use of true ICAI systems will undoubtedly occur, but not for 15-20 years.

Dr. Marlene Jones Colbourn, Department of Computer Science, University of Waterloo, Waterloo, Ontario, discussed "Experts Systems: Their Potential Roles Within Education." An expert system is defined as an automated consulting system designed to provided the user with expert advice within a particular subject area. Most ongoing projects are still prototypes, and include use in chemistry, medicine and geology. System components include adequate interface to interact with the user, a database for the particular case, a knowledge base with problem-solving skills, workspace to store intermediate results, a control structure to select rules and apply them, and a justifier to ask why the decision was made. Building an expert system requires an intitial knowledge base design to define the probelm, break it down into smaller problems, and determine how to represent them appropriately; prototype development and testing; and refinement and generalization of the knowledge base.

In education, expert systems have two principal roles: instructional computer-assisted instruction (CAI) and diagnosis. One expert system assists in assessment of reading problems and is an initial step in developing a system to guide a teacher through stages of diagnosing learning disabilities. The same tools and techniques used to develop ICAI systems can be used to develop appropriate systems for children with specific learning disabilities and for children who are mentally handicapped, visually impaired, etc. Development of diagnosis an assessment systems is clearly feasible and could include an appropriate remedial program. Despite major advances in artificial intelligence, Dr. Colbourn stressed, the task of developing an expert system within any complex domain remains challenging.

Dr. D.L. Kimbler, University of South Florida, discussed "Robots and Special Education: The Robot as Extension of Self." He examined the use of robots as an aid to the physically handicapped, the requirements for robot performance, and the research agenda necessary for the use of robots in special education in the future. The robot should operate to assist the handicapped student to become as nearly fully functioning in the student's environment as possible. The main conditions that would be alleviated are those that limit mobility, dexterity, and interaction with the environment, such as orthopedically handicapped, and visual impairment and deaf-blind. Primary common characteristics in the robot extension would be mobility, dexterity, payload capacity, sensory capability, and intelligence. These characteristics are presently found, singly or in limited combinations, in existing robots. It is in the combination of these characteristics that the useful fully functioning robot is defined. Existing systems that come closest to them are the mobile educational robot systems, but they are at a much lower level than what is required.

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Considered only as an aid to the handicapped, research to bring the desired robot into development could be thought too expensive. But this robot and its counterpart for general use will differ only in adaptive input and output devices, if at all. This puts a different light on its economic viability, and provides a unique opportunity to special education. At a cost of $10,000 per robot the initial cost to give all students in these categories a robot, would be $2.5 billion with succeeding costs of $125 million annually plus R&D costs. Cost/benefit analysis needs to be done involving, both public and private sector funding sources. But if the robot can be used more broadly in general education, special education cout can take a leadership role in its development and then make it available to the rest of the world years sooner than it would otherwise come to be.

5. RESEARCH IN OTHER FEDERAL AGENCIES

Representatives from the Department of Defense, National Aeronautics and Space Administration, National Institute of Education, National Science Foundation and Utah State University summarized current research activities on artificial intelligence, robotics, and related areas.

Robert A. Wisher, Office of the Undersecretary of Defense for Research and Engineering, discussed defense applications of AI for training and education. He described three research projects that are challenging important AI issues and developing fundamentals for intelligent computerized "tutors" that can provide expert guidance and feedback to a broad range of learning activities, including special education.

One project is developing a computer gaming system designed to improve reading skills. A second focuses on techniques to help computer programmers better understand the programs they write by developing techniques that will automatically diagnose and correct misconceptions that cause incorrect computer programs to be written. The third involves development of an expert's mental model of an automotive ignition system to explore approaches for representing an expert's knowledge in a computer- based instructional system and then develop procedures to enable a novice to take advantage of a computer's wisdom.

Donald Lokerson of NASA's Goddard Space Flight Center's Instrument Division described research activities relevant to special education at NASA. These include work on decoding speech and adapting a speech decoder for speech recognition that would be suitable for CAI, speech evaluation and therapy and documentation for the assessment of the progress of therapy.

Another development implemented by the Veterans Administration was a wearable cued speech lip-reading display system which is close to becoming a viable commercial prototype.

Paul Resta of the National Institute of Education reported that NIE considers technology a critical component within the total educational process. He noted that major elements for which technology is important include long-term cognitive effects, social interaction, and motivation, especially for younger children working on computers. A wide range of R&D projects include effective strategies for programming and for introducing technology in the classroom. Major emphasis is on the instructional process to improve the quality of instruction using technology as a tool. He reported that the Educational Technology Center at Harvard University is establishing targets of difficulty in exploring how technology can help learning, to determine if applications of technology can be part of the solution. They are using a mix of technologies, including interactive videodiscs, speech recognition devices, and broadcast media. In the coming year, there will be more advanced applications, with a prototype for computer-based learning environments.

He warned that the information age offers broader alternatives to educators, so that those we want to keep in special education will be courted by other disciplines and by industry. "We need to provide flexible opportunites and alternatives so we preserve what we have and do not lose people we have invested in as doctoral students. In the information age, knowledge assumes a level of negotiability we never had before, and we have to preserve and capture that knowledge."

ISSUES AND PROBLEMS IN DEVISING A RESEARCH AGENDA FOR SPECIAL EDUCATION AND TECHNOLOGY

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Much of what I have been saying of late, in speeches both about and not about technology has had to do with Psychology and nothing at all directly or, rather, immediately to do with Information Technology and this reflects a large problem area that needs attention by people working in the various domains of Educational Technology. Let me first establish that my concerns are not merely a personal eccentricity. In fact, I have some pretty good company.

In the January/February issue of the Harvard Business Review, Peter Drucker wrote a small piece called "Our Entrepenurial Economy" in which he threw away the following statement:

> Within the next fifteen years we will surely see the most profound changes in the way we teach and learn since the printed book was introduced 500 years ago. The computer has, of course, a highly visible part to play here, but the real agent for educational change is the new scientific knowledge we have gained since Wilhelm Wundt in Germany and William James in this country first asked, 100 years ago, "How do we learn?"

Evaluation of Microcomputer Courseware. I have a work in progress entitled "Will Word Processors be the death of the "English language" the major thesis of which is that as it becomes easier and easier to produce words less and less care and attention is being given to the selection of them or to their grammatical and syntactical arrangement and that the result is a lot of virtual gibberish of which Ragsdale's book is an unfortunate example. Unfortunate because if you do slog through it you find some quite important notions. I said the book was misleadingly entitled because it sounds like a cookbook on how to evaluate courseware when in fact it is a book the holds up both the development of courseware and the evaluation of courseware against theories of instructional design and theories of evaluation. He finds, and I concur fully, that under such scrutiny most courseware fails miserably on both counts, design and evaluation. Courseware developers get very defensive when you say this. I once mentioned this to Jim Poirot and Jim sort of arched his back like a cat about to pounce and said "You don't demand that of textbooks", to which I said simply, "I rest my case". Ragsdale's thesis is straightforward even if his prose isn't:

> (Adequate design approaches) must be based on knowledge of how humans learn...Components of the design document (for the courseware) should include statements of goals and objectives. This (sic) should be supplemented by a learning map indicating the skills to be covered and those prerequisite hierarchical relationships among the skills, and a suggested sequence for presenting the skills.

Well that's just fine except for one thing: Even though it's been a hundred years since Wundt and James asked how do we learn, we still do not know nearly enough about what learning entails.

Wundt and James were not, of course, the first people to ask this question. People had been asking it for centuries, but Wundt and James changed the nature of the *process* by which we began to look for an answer. Prior to Wundt and James, in Western society anyway, psychology was a branch of philosophy and subject to the same "armchair" approaches as ethics, aesthetics and so forth. After Wundt and James, psychlology emerged as an endeavor of *science* with all the empirical and experimental implications that such a change carries. Unfortunately, a large segment of pyschology, in England and the U.S. anyway impeded by the dual curse of behaviorism and methodological obsessionism. In an attempt to establish psychology as a legimitate science, many psychologists emulated the methods of physics, *Newtonian* physics, yet, to the detriment of establishing what is the appropriate *content* of psyhology. I believe that when we get far enough away from it so that too many egos are not endangered, we will look back at the period from roughly 1920 to 1960 as the dark ages of psyclology. I recall well a day in 1964 at Stanford when a fellow graduate student of mine and I were discussing the problem with Hull's theory of behavior. The theories of Clark Hull were without doubt the most ambitious attempt to apply the hypothetico deductive theorems for a psychology of learning. It was not small source of embarassment that some of the postulates were found to be contradictory. Paraphrasing Churchill, my friend said "never have so many wasted so much time to learn to little." True, alas.

"Cognitive" is a good word these days. So is "metacognitive" even though nobody knows what it means. At Stanford, and similar institutions in the mid sixties, you risked your reputation using cognition. Unless you were willing to be considered something of a wimp, like Al Hastorf, or a flake like Karl Pribram, or unless you had a lot of chutspah like Leon Festinger who would have been the author of Winning Through Intimidation, "cognition" was a word you left out of your vocabulary or whispered to close friends at parties far from Cubberley Hall.

Not all psychologists were carried away with the hypothetico deductive method. A certain B.F. Skinner made quite a reputation for himself by poking fun in all seriousness at the endeavors. In 1950, in an article entitled "Are Theories of Learning Necessary" he concluded that that answer was "no". All the hypothetical constructs of Hull and similar theorists added nothing to our understanding of how people learn. Wrote Skinner:

> When we attribute behavior to a neural or mental event, real or conceptual, we are likely to forget that we still have the task of accounting for the neural event. When we assert that an animal acts in a given way because it expects to receive food, then what began as the task of accounting for learned behavior becomes the task of accounting for expectance. The problem is at least equally complex and probably more difficult.

Skinner, of course, went on to argue to forget about mental and neural events and hypothetical constructs and concentrate on overt behavior.

Special education during this period suffered an additional curse, the development of the IQ test and similar psychometric abominations. There was a schism between psychology and education and education was lucky enough to get the branch of psychometrics which developed as a field largely without any theoretical underpinnings at all or derived its theoretical constructs from the results of Techniques, most notably factor analysis. As Howard Gardner notes early in his recent book Frames Of Mind: The Theory Of Multiple Intelligences.

> It (the IQ) is based simply on tests with some predictive power about success in school and, only marginally, on a theory of how the mind works. There is no view of process, of how one goes about solving a problem: there is simply the issue of whether one arrives at a correct answer... An individual can lose his entire frontal lobes, in the process becoming a radically different person, unable to display any initiative or to solve new problems - and may continue to exhibit an IQ close to genius level.

Gardner's comments apply with equal force to the overwhelming majority of tests. In an article which unfortuantely I cannot find, Henry Dyer, a longtime employee of Educational

Testing Services argued that test scores were so far removed from the behaviors that they purportedly summarized that people should not be permitted to discuss behavior when talking about them. In 1977, Oscar Buros delivered a speech to the American College Testing Program whose achievement battery is almost as widely used as the S.A.T as a college entrance requirement. In it Buros, the founder and editor of the Mental Measurement Yearbook, argued that:

> Most standardized tests are poorly constructed, of questionable or unknown validity, pretentious in their claims, and likely to be misused more often than not.

He went on to proclaim that in general things in pyschometrics had gone downhill since 1927. Given that he did not mention criterion referenced tests specifically and that these tests were not so much in vogue, I called him and asked him first if he really felt as strongly as he indicated in his paper about how norm referenced tests and what he felt about criterion referenced instruments. He said that his paper understated the case. "I told those good gentlemen," he told me, "that they were doing an incredibly fine job of all the wrong things". In response to my query on CRT's he said "From what I have seen people are beginning to do a relatively poor job of some of the right things."

I'm happy to report that, at least in my opinion, there are now more good jobs of right things being done. I am sad to report that, as evidenced by the unfortunate use of test results in the various educational reform commissions, by what I hear daily about test usage in various state and localties and by Secretary Bell's "wall chart" of SAT and ACT data, the good things have not yet made their way into general public awareness.

Influence of Piaget. The person most responsible for changing our attitudes towards learning and cognitive development was Jean Piaget. After a flurry of favor in the thirties in America, Piaget fell out of favor and was rediscovered in the sixties. Again, when I was in graduate school, people were busy trying to explain away Piaget's conclusions as the result of poor methodology. They couldn't, but many a developmental psychologist became a Piagetian not in the laboratory but at the dinner table. I too have had this experience and I can tell you that nothing can compel a belief in concrete operations or the lack thereof more than to watch your five year old systematically divide a piece of cake or other dessert in order to make it more, and for you to try every means you can think of to convince that child, unsuccessfully, that the quantity is constant. There is an even more compelling example. In most households parents are scrupulously careful to give siblings equal quantities of everything unless, of course, one of the siblings is a teenager in which case all bets are off. Parents are not always so careful, naturally, about their choice of containers and it is not unusual for two children to receive equal portions of everything and to have one to began to cry about getting less and when you look you notice that the glass with "less" is wider than the glass with more and so the orange juice or whatever doesn't come up as high.

I don't want to paint Piaget as a savior of psychology although he did break the noose of behaviorism in many respects and oriented us to the process of learning. But his theories have been found to be circumscribed in some areas and in need of repair in others.

Piaget, after all, is often described as an empirical Kantian and much of his work had to do with the development of what Kant had called "categorical imperatives".

Piaget, like so many philosophers before him was concerned largely with how the child comes to make sense of the physical world. He thus ignored many other attributes of mental functioning. Among those overlooked are many that would be of importance to special education.

In the terms of Howard Gardner's multiple intelligences, Piaget paid little or no attention to musical intelligence, bodily-kinesthetic intelligence, spatial intelligence, or the inter and intra personal intelligences except in terms of general moral development and even there his concern was with universal rule systems and, of course, his work as well as that of Erikson and Kohlberg has been rather effectively challenged by Carol Gilligan in In Different Voice.

Gilligan charges that all the experiments based entirely on male subjects did more than just reduce the variance of the results. They overlooked an entirely different mode of experience and different moral system.

So where does all this leave us with respect to Technology and Special Education? It leaves us with a rather considerable burden, I'm afraid. It leaves us with the burden of developing materials while our knowledge of how people learn is in a great state of flux and while the measures of effectiveness -- tests -- have not undergone an adequate reform to be necessarily available and/or appropriate. It means that in any research or development project, the variables to be manipulated and the instruments used to measure the success or failure of the experiment must be chosen with extreme care.

Gross and Ill-Defined Research. I do a bi-monthly summary of research pieces for *Phi Delta Kappan* Magazine and in the first one I had a long piece devoted to what I called context and in which I cited an article by Dave Berlinger of Arizona. What Berlinger argues, and I concur, is that many if not most of our treatments in education are so gross and ill-defined that it is virtually impossible to get good measurement on their effectiveness even if we have a fully adequate system of pyschometrics. "Educational treatments, such as teacher centered classrooms, open education, new math, and seatwork are not precise concepts". To finally bring this paper around to the point of this symposium, I would argue that similar problems attach to the phrases CAI and CMI. It thus makes no sense to me to argue as Glenn Fisher did in recent issue of Electronic Learning, that CAI is effective here, not effective there, somewhat effective over there under certain conditions. In fact that article was published over strenuous objections from me which is probably why the people at *Electronic Learning* have not called me in a while to act as an Editorial Adviser to their research section. In fact, my activities in relation to *EL*, I think are instructive for the outcomes of this conference.

In November of 1982 *EL* published a cover article I wrote on CAI effectiveness, what the research shows. Apparently highly favorably response because we started talking about making research a regular feature, maybe even bylined, for the magazine. Even though I had advised them on a number of pieces, some of which have been published, some of which have not, my feeling is that the project in general has fallen through for a variety of reasons.

Shortly after the piece was published I attempted to update it both for personal interest and for use in the periodical. I haven't been terribly successful. In the first place there is no counterpart to the Council for Exceptional Children or Society for Research in Child Development or other groups. There is now, I note a special interest group within AERA but I don't know what they're doing. The point is that people doing research with computers are a very loosely coupled group. You can pick up some through ADCIS, and some through AEDS and some through NECC, but they're not a focused group. Ron Anderson of the University of Minnesota sent me a prospectus for a journal of research in computing that Robert Seidman was putting together, but I haven't seen the journal yet. I sent a query over the electronic mail system of the Council of Chief State School Officers. I sent a letter of enquiry to almost 100 people who were at a computer literacy concerence that Andy Molnar and colleagues at NSF put together. I got maybe 25 responses, some of which were updates of usage, not research, some of which said essentially "we're too busy doing things to do research but your project is important. Good luck". The following excerpt is atypical only in its lenght:

> I have been in the Educational Technology field for almost 25 years and am appalled at the casual way we are approaching the new technologies. The relative importance of understanding earlier rather than later the effectiveness of various computer aided instructional techniques and programming approaches could lead to far more productive investment of scarce time and dollars.
>
> In the educational world we are running a great risk of incurring a backlash against computers and computer aided instruction if we do not identify and systematically employ demonstrably effective approaches.

I have seen little in the way of such systematic identification. Indeed, just the reverse. Hyping computers may be tolerable if undesirable by manufacturers, but you would think that after all the years of education' relationship with technology, after radio and TV and learning machines and programmed texts, a relationship that more than one commentator has called "disastrous", we might be a little more systematic in our approach and cautious in our claims, but I see a lot of caution to the winds statements. To date, most of the claims for Logo have not only been unsubstantiated, in some instances negative evidence has been gathered.

In the November, 1983 Computing Teacher, Dorothy Derringer listed ten new tools to prepare for the third wave. Among other things she wrote:

> Do you wish to stimulate logical and creative thinking in young people? These materials from Ann Piestrup's The Learning Company do it! Rocky's Boots, a game with the content of a logic course, appeals both to third graders and to graduate students.

Now I haven't met an adult who didn't enjoy Rocky's Boots, but when I checked with Charles Fisher at the Far West Regional Laboratory who has a grant to study the cognitive outcomes of a lot of things including Rocky's Boots, he couldn't provide me with any data indicating that it stimulates logical and creative thinking. Indeed, we agreed that Rocky's Boots, while it might be as good as anything else and better than most is not, in and of itself, going to be a powerful enough treatment to show much of anything. I'm not suggesting that we should pull Rocky's Boots from the classroom, but we should be very careful about making grandiose claims that are subject to empirical refutations.

Policy-Making and Research. In fairness, I should mention a serious impediment to research in computer assisted instruction. You see it a lot in the area of policy making. I often fume at my boss because he makes policy decisions in the absence of what I would consider adequate data. My boss often fumes at me because I can't get him that data fast enough. There is a tension, perhaps irreconcilable between the plodding methodology of research and the often frantic methodology of policy making and it looks like it will get worse. As Information Technology makes it possible to move information around rapidly, people then feel an obligation to move it around as fast as the technology permits. This problem has produced a new term "technostress" and a new disease flippantly called "life pace attack" which occurs anytime that the world is moving more slowly than you want it to. I've noticed it myself in impatience in waiting for my $13,000 Word Processor to work as fast as I can work it. Research methods currently available however, demand care and time if not sloth so I am not sanguine about research and policy in the near future.

Recent Fingings. Let met review for you now a few things that I have come across that seems strenghened since I wrote my article in 1982.

1. I noted in the article that I and others had seen more collaborative problem solving by children using computers than usual. I think it is too bad that an economic expediencey - we can't afford a computer for every child - is what it took to break the typical classroom situation in which cooperation is called cheating. Nevertheless, there is some data here now that even when the opportunity for cooperation is factored out of the equation, children using computers cooperate about three times as often as children using traditional curriculum materials. Karen Sheingdd and colleagues at Bank Street have data on the same phenomenon.

2. Computers seem to be especially effective in the instruction of low achieving students. Again, no one knows why this should be the case, but it is not unreasonable that the ability to set the pace, to avoid embarassment and enjoy the unending patience of the computer has something to do with it.

3. Although not a product of hard research, people who work with computers and special education students feel that they gain a sense of control over their world that is not readily available to them under either mainstreamed or contained classroom conditions. No one has measured changes in locus of control, which is a pity because it is associated with a number of positive pyschological outcomes and if using a computer increases a child's sense of internal locus of control - of being the captain of his or her fate - that would be important to know. Terry Rosgrant of Arizona State who works with

handicapped children and computers feel very strongly that computers have this effect but has no "hard" data to support it.

I would like to turn now from data to some issues that must be considered in any research or development project concerning computers.

The first of these is how do you evaluate the outcome? Is proper to use a paper and pencil test to compare the outcome of CAI with an outcome using paper and pencils as the medium of instruction? In an article entitled "Preserving the Integrity of the Medium", Mary Alice White and her colleagues at TC have argued very strongly no. Her particular concern at the time was television, but a similar concern would apply to computers or any medium. In this conncection I think it makes absolutely no sense to argue as Richard Clark did recently that

> The best current evidence is that media are mere vehicles that deliver instruction but do not influence achievement any more than the truck that delivers our groceries causes changes in our nutrition. Basically the choice of vehicle might influence the cost of distributing instruction, but only the content of the vehicle can influence achievement.

I think that is absolute nonsense.

To use Clark's metaphor, imagine tow trucks, one refrigerated one not delivering loads of lettuce to Washingtion from Calfironia imperial valley. I think that the choice of vehicle might influence nutrition.

Clark argues that from his point of view all media arrive at the same destination and are therefore equivalent. Tell that to Federal Express. I think that Clark's article begs the entire question of media attributes and effectiveness. I am much more in accord with Philip Oltman of Educational Testing Service who in his 1983 monograph wrote:

> Any given medium, be it print, radio or television, is not simply an envelope in which to send a message; it is itself a major part of that message. Changing the medium does not leave the enclosed message unchanged. As (Neil) Postman says, the printing press, the computer and television are not simply machines that convey information. Like language, they are different windows on the world, each with its own optical properties. Each medium's peculiar refraction is due to the properties of its symbol system.

Inappropriate Research Instruments. I would argue that we know very little about the "peculiar refractions" of computer assisted instruction partly because we've been trying to study them with instruments designed to measure the peculiar refractions of print media. I recently received a report from Bob McAndews' School of Management and Strategic Studies which is an almost totally computerized course of study. One of the first "graduates" of this two year course was quoted as saying "never before in history has the student and his contribution been in the same medium and the same context as the instruction and his material." A grammatically incorrect, but intriguing statement.

(I am often reminded that Socrates argued that the general populace should not become literate. That reading would destroy the great oral tradition and make minds lazy. I often wonder what Gutenberg would have done if Socrates view had prevailed. Would he have invented a Victrola or a camera or some other medium? I muse too over whether it was this kind of consideration that Frank Herbert had in mind in Dune when he had his civilization destroy all computers used for education with the realization that no computer could ever compete with a properly trained mind)

I have come across many studies in cognitive psychology lately showing that students have fundamental misconceptions about many concepts in physics. At least some of these errors seem to be due to the fact that students can't free themselves of everyday reality which includes gravity. In my earlier research I found a study where students learned conservation of momentum better using a computer than with the traditional laboratory apparatus, and the most plausible reason was that it was easier to simulate a gravity free environment using a computer.

Secondly I am quite concerned that many of the older studies that showed improved learning using a computer will not hold up in the current context are being used. A friend of mine at the College of William and Mary, George Bass, conducted a research study of math achievement using Apples in classrooms and found significant differences in favor of CAI, significant differences favoring traditional instruction and, most commonly, no significant differences. Why? Well think for a moment about the conduct of earlier studies. They were usually designed as research, conducted in laboratories or special rooms by people who were experts in both the subject area and the machines and so forth. More recently we have been using smaller machines in classrooms with programs administered by teachers. An article I saw recently began "for the 90% of the population who do not use a computer..." 90%! What kind of an information age is it where 90% of the population of this country does not use a computer?

Roger Ragsdale in the earlier mentioned book also noted that the use of any courseware, validated or not, needed to be examined in the light of the context of its validation versus the context in which someone else planned to use it. Given the cottage industry nature of courseware development for many educational applications, I think that that is advice well offered.

My guess, and at this stage it is no more than that, is that the reason CAI and its related information technology treatment are likely to be more effective, utlimately, than treatment such as television or traditional material is that it is interactive. Piaget and all biologically oriented theories of learning posit an organism that is actively trying to make sense out of the world as it matures. Recent research with infants shows this dramatically. I think the fact that we worry about television being the plug-in drug, a device that overrides this powerful biolog- ical instinct and induces passivity, tells us something about the schools and the culture to which our children are typically exposed and that that something is not good news.

Is Effectiveness Research Irrelevant? Finally, I would point out that where the computer makes possible something not otherwise possible in a child's experience, then research on "effectiveness" is irrelevant. I mentioned a study of conservation of momentum in physics. Think of the generations of fruit flies you can breed in a class period. Or of the musical experiences available through keyboards or even the sound capabilities of the machines. Or the art packages. I make no pretense to expertise in Special Education, but it would seem to me that *Electronic Learning* was on target in the February 1984 issue when they referred to Technology and Special Education as natural partners.

Some of the simulations I have seen are not particularly good because of the cottage industry production and the memory limitations of the machines and the attempt to keep costs down, but those are limitations fast disappearing. In 1978 a 16K machine was considered an OK device by a lot of people. Is anything coming out these days with less that 128?

It has been said that the way we have used computers to date is like asking a symphony orchestra to play scales. As cognitive pyschologists provide better and more complete answers to "how do we learn?" I think computers will be seen more and more as useful instruments to aid learning. We may, like the people of Dune ultimately abandon computers as tools for training the mind. In the meantime, we must use our ingenuity to make them make music rather than play scales.

MACRO-RESEARCH ON TECHNOLOGY; MICRO-RESEARCH ON EDUCATION

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Abstract

Computer-assisted instruction (CAI) is an integration of two earlier technologies: computers and programmed instruction. CAI is also an extension of methods originally developed for the experimental analysis of learning. Research on CAI has placed the focus on the technology itself, rather than on the process of learning from media. This emphasis is unfortunate and tends to reinforce the misleading assumption that "technology solves problems." In fact, the benefits of CAI should more appropriately be attributed to instructional method and novelty.

A paradigm for future research is proposed. Macro-research will investigate issues related to the implementation of technology in schools; micro-research will concentrate on the process of learning. Case study methods are advocated as a sensible alternative to stochastic techniques under some circumstances. The role of the special education teacher is considered: effective use of CAI converts teachers into "educational researchers." Research on ways to improve teachers' knowledge of educational principles, as well as technologies, is recommended.

Macro-research on Technology; Micro-research on Education

The experimental apparatus consisted of...........

For more than a century, research psychologists have used a variety of special devices -- some elegantly simple, some inordinately complex -- to assist them in measuring and determining the effects of different learning strategies. Some of the more rudimentary devices, such as a "memory drum," controlled only the rate of presentation for stimuli in, for example, verbal learning tasks. Over the course of time, technological improvements (particularly electronics) and the ingenuity of researchers have led to devices that controlled presentation of both discriminatory and reinforcement stimuli (cues and rewards or punishments) and recorded, in detail, the progress of learning.

A culmination, of a sort, in the development and exploitation of this technology was reached in Skinner's studies of operant conditioning (for a review, see Skinner, 1961). Through relatively complete control of the learning situation, pidgeons and rats were taught to perform complex and unexpected behaviors. The sight of pigeons seeming to "read" miniature traffic signs ("turn right," "turn left," etc.), or proceeding to play a sharp game of ping-pong.....these demonstrations, often recorded on film, convinced many psychology and education students that something remarkable had been discovered.

Unfortunately, these demonstrations also tended to confuse two separate issues:

(1) the investigation of the principles of learning; and

(2) the use of machines in the delivery of instruction.

In the research setting, the use of such mechanical devices was purely a means to an end. The experimental apparatus was designed solely to provide a reliable and efficient mechanism for testing components of learning. For the researchers, there was no confusion about the aim of the investigation. If the subject was paired-associate learning, it made little difference whether the experimental method used a memory drum, a slide projector, a tachistoscope, or a video monitor.

Alternatively, not all psychologists were interested only in basic research. Some (and Skinner is a prime example) recognized that the instrumentation from the laboratory could also have some generalizability to more typical educational settings. This notion led initially to the proposal of controlled environments for learning (e.g., the "Skinner box" and the society envisioned in *Walden Two*[1] and subsequently to the introduction of programmed instruction (Skinner, 1968).

In fairness to the early advocates of this transfer of laboratory methods to the *real* world, they should be credited with understanding that the mechanical devices were not themselves the source of the intended benefits to instruction. The "teaching machines" were simply the vehicles through which principles of instruction, learned in the laboratory, could be replicated in the classroom. Teachers could also apply these principles, and they were encouraged to do so. The machines, however, offered an opportunity to increase the amount of individualized and controlled instruction that could be offered in the classroom.

Nevertheless, technology has a certain appeal above and beyond its immediate usefulness or benefit. Human beings have a historical fascination with new technologies. A friend of mine recently commented that she had come to realize there were "too many internal combustion machines in [her] life." She had counted them up and found that she owned eight: from her station wagon to her gas-powered "weed whacker." Each required a different fuel mixture, and some degree of special maintenance during the average year. She had resolved to get rid of at least some of them in the near future...but which ones?

Her comments were made at a small dinner party attended by eight educational researchers, and sparked a lively discussion of the bizarre and extensive inventories of mechanical and electronic appliances that each of us owned. Seated around the table, each of us recounted the more unusual and arcane technologies that we possessed. We enjoyed each other's excesses in pioneering technological innovation. Nevertheless, I could not help but notice my own pangs of remorse when someone mentioned any item that I, too, did not own.

Beyond this example of my own covetousness, I think there's a basic belief in most people that technology solves problems. I know that many people are now talking about our time as the beginning of the "Information Age" and the end of the "Industrial" or "Mechanical Age." However, I recall when the twentieth century was sometimes referred to as the "Age of Invention."

I also recall when I was a teaching assistant for the course "Introduction to Learning" at a graduate school of education. Most of the students were education majors and they were required to take the course. Each year we showed the film of Skinner's Pidgeons..."reading" stop signs and playing ping-pong. The film always made quite an impression. I'm sure many of those students, who are now teachers and administrators, remember those images -- of the pidgeons' performance and the training cages. I'm not as confident that they remember, as well, the intricacies or import of discrimative stimuli or varying schedules of reinforcement.

Computers in Special Education

What happened to "teaching machines" and programmed instruction?...not much. Actually, that technology was replaced by another -- computer-assisted instruction. The computer has a great advantage over the earlier teaching devices: it is flexible. In fact, that feature represents a critical distinction between "devices" and computers. A teaching machine is a device; it is designed and programmed to perform a fairly limited function. A computer, especially as represented by more recent models, is a "medium;" it's potential applications are almost unlimited. (Many early computers were "dedicated" to specific functions; they were more like devices than like media.)

This feature of flexibility was identified early by researchers and educators as a clear advantage. In the laboratory setting, the computer interface has now become almost completely pervasive. Beginning in the 1960's, computer-based applications in instruction have also proliferated. During the sixties and early seventies, this growth was slow. However, during the past few years it has accelerated rapidly, due largely to the introduction of microcomputers (Hannaford & Taber, 1982).

A computer is a computer is a computer. The essential difference between a large computer and a microcomputer is one of cost. Microcomputers have made the use of this technology in education affordable.

The flexibility of the technology has also expanded the types of applications that can be made in schools. In addition to instructional applications, computers can also be used for administrative applications. In the area of special education, a very broad range of possible applications have been envisioned.

These include:

1. Instructional Applications
   - Computer-assisted instruction (CAI)
   - Computer-managed instruction (CMI)
   - Computer literacy
   - Computer programming/science
2. Administrative Applications
   - Financial management systems
   - Information management systems
   - Special systems (e.g., IEP development and management)
   - Word processing and mailing
3. Impairment Compensation
   - Sensory
   - Communication

- Physical control
- Personal management
- Vocational opportunity

Special educators have, in fact, been pioneering propagandists for the use of computers in the schools (Cartwright & Hall, 1974; Hallworth & Brebner, 1979). Given the benefits atributed to individualized instruction, and the demands that legislation and special education policy made on schools to provide "comprehensive services," computers have been envisioned as potential problem-solvers across a broad range of service delivery requirements.

The penetration of microcomputers into special education programs is increasing dramatically. It has been estimated (Education Turnkey, 1983) that the number of microcomputers used for instruction in special education will increase 800% from 1982 to 1985. A recent survey of microcomputer use in schools (Market Data Retrieval, 1983) reported that about half the local special education programs in American school districts, and one-third of the special education teachers, reported use of microcomputers.

I cannot think of any other technological innovation which has had such a rapid and pervasive impact on the practice of education. As an educational researcher, I am also very concerned about the long range effects of this development and the current paucity of empirical research that would support such a sweeping transformation in our approach to providing education for handicapped students. Having presented some background to this issue, I will turn now to the research which has been conducted and suggest some directions for future study which, I hope, will guide us in the appropriate use of a technology that, for good or bad, is clearly present in the schools.

What do we know about CAI?

During the early 1960's, most of the initial work on computer-assisted instruction (CAI) was conducted in research-oriented, university settings: Stanford University, University of California at Irvine, University of Texas, Florida State University, University of Illinois, Pennsylvania State University, University of Pittsburgh, State University of New York at Stony Brook, and Harvard University (Atkinson & Wilson, 1969). Philadelphia (1966) and New York (1967) were the first two local school districts to implement CAI. Many of these early projects produced research reports.

Vinsonhaler and Bass (1972) summarized the findings from 30 separate experiments that compared traditional instruction (TI) to TI augmented by CAI "drill and practice" in elementary level instruction. They concluded that the added CAI was more effective than TI alone.

In what is now considered a classic review of the available research, Jamison, Suppes, and Wells (1974) examined the effectiveness of a variety of alternative instructional media, including CAI. Following a summary review of many studies, they concluded that "no simple uniform conclusions can be drawn about the effectiveness of CAI" (p. 55). At the elementary school level, they found that CAI was apparently effective as a _supplement_ to regular instruction. At the secondary and college levels, they concluded that CAI was a reasonably effective _replacement_ for TI and could possibly lead to savings in instructional costs and student time.

In the following year, Edwards, Norton, Taylor, Weiss, and Dusseldorp (1975) reported their results from a review of the CAI literature:

- CAI was in many cases more effective that TI for short-term improvements (e.g., final examinations), but did not necessarily lead to long-term gains (retention);

- CAI sometimes reduced the time requirements for students to learn material;

- Overall results for CAI, when it was used as a replacement for TI, were equivocal--about half the studies showed gains for CAI; half showed advantages for TI, or no difference.

These early syntheses of the research employed a simple "boxscore" approach: results were treated as either favorable or unfavorable. Reviewers compared the proportion of studies that fell in each category; they also provided some narrative description of specific findings or details in the studies.

An alternative approach to the review of this literature was initiated in the late seventies; Hartley (1977) was the first to use meta-analysis (Glass, McGaw, & Smith, 1981) to attempt to quantify the effectiveness of CAI. Subsequent meta-analytic reviews have been conducted by Kulik, Kulik, and Cohen (1980), Burns and Bozeman (1981), Kulik (1981), and Kulik, Bangert, and Williams (1983). Each of these reviews reported favorable results for CAI compared to other teaching methods: effect sizes for gains in student achievement ranged from .1 to .45 standard deviations. These reviews have been noted by other researchers as evidence of the "effectiveness of CAI" (Bracey, 1982; Fisher, 1982; Bright, 1983; Bear, 1984).

Among the referenced meta-analytic reviews, the study by Kulik, Bangert, and Williams (1983) is the most recent. For 48 studies with results from students' final examinations, students who had received CAI outperformed students who had received only conventional instruction in 81 percent (39) of the cases. The average effect size was .32 standard deviations. This suggests that in the typical class, the CAI students performed at the 63 percentile on the final examination, in comparison to a 50 percentile performance for students who received conventional instruction.

However, there was a wide range of variablility in the results reported across the 48 studies. In nine cases, the students who received conventional instruction did better on the final examinations. The effect of CAI was moderate in the typical study, but ranged from a negative impact of .75 standard deviations to a high positive impact of 1.75 standard deviations. The standard error reported for the average effect size (.32) was 0.061; in other words, at the 95 percent confidence level, the estimate of the typical effect size could range from .20 to .42.

Research on the use of CAI in special education has been scant. Although interest in the use of computers with handicapped individuals has been strong for some time (Brebner & Hallworth, 1980), most of the studies in this field have been small and have concentrated on substantively different applications with different handicapped populations. It is difficult, if not impossible, to generalize broadly from such diverse experiments. Nevertheless, there is "evidence to support CAI intervention with a variety of handicapped populations" (Hofmeister, 1982, p. 117).

A recent example of such research is the study conducted by McDermott and Watkins (1983). They investigated "Computerized vs. conventional instruction for learning-disabled pupils." Their study is notable because it incorporated many features of good quasi-experimental research -- features that are sometimes lacking from educational studies: random assignment of subjects, comparable treatments, pre and posttest measures, and other statistical controls (repeated-measures analyses).

In their study, 205 first-through-sixth-grade learning disabled students were assigned to either a mathematics CAI or spelling CAI treatment group or to a conventional instruction group. After one school year, posttest performance for the groups was compared (and covaried to control for IQ, pretest performance, and other factors). They found that achievement gains for the three groups were essentially equivalent. They concluded that:

> ...the two methods [CAI and conventional instruction] may be substituted for one another as instructional procedures. Assuming similar degrees of effectiveness and efficiency, it might be reasonable (a) to assign such pupils to CAI programs whenever it appears that this will reduce the motivational deficits and resistance so often detected among problem learners, and (b) to recommend special teacher-instructed programs whenever affiliative needs and social conditioning are deemed priorities. (p. 87)

The effectiveness of CAI--a non-question.

I am satisfied that electronic media can be used to provide or supplement instruction. Based on the research in this area, and on observation of its use in actual classrooms, I am also convinced that it can be very useful in some situations and equally useless in others. The variability of results reported in the literature reflects this viewpoint. Nevertheless, I have mixed feelings about reports that "CAI is effective." As an advocate for improvements in instructional methodology, I share the enthusiasm about the potential value of microprocessor-based applications for handicapped people:

> It would be impossible to quote an exhaustive list of the special functions microcomputers could provide for disabled individuals. Almost any aspect of human activity that has been impaired could potentially be aided to some degree through the use of microcomputers as processors, manipulaters, or controllers. (Vanderheiden, 1982, p. 138)

Consequently, I'm glad that there is a body of literature that provides evidence in support of introduction of these technologies into schools. This information can be very helpful for convincing school administrators or policy-makers that microcomputers (or other new technologies) are worth trying.

On the other hand, a "hidden message" in this conclusion is the old saw that "technology solves problems." Some educators and parents may believe that the simple introduction of this technology will lead to an improvement in the instructional process. In fact, it is not the technology itself but the specific use of the technology that will affect student achievement.

At issue--media attribution...

Much of the research and even more of the general writing about CAI has focused on the technology itself. This is a problem because it reinforces the notion that technology solves problems and it suggests to educators that acquisition of technology is a paramount concern. When I talk with teachers, the two most common questions they ask are "What kind of microcomputer should I get?" and "What software should I buy?"

This concern with technology, per se, has been common in education for the past 60 years (Tyler, 1980). A variety of media, devices, and systems have been introduced with much ballyhoo and promise. Most of these have wound up underutilized, finding a significant place in only a small number of classrooms. In part, this failure of many new technologies resulted from inaccurate perceptions by educators regarding the role of technologies. Two common fallacies (cited by Tyler) are:

> [1. a] misleading assumption that teaching is mostly, if not solely, presenting material to students... [; and

2. a] misleading assumption that teaching is primarily a technical activity, whereas, in fact, it is a human service. (pp. 13, 14)

In contrast to such popular misunderstanding of technology, a small but growing number of educational researchers and theorists have attempted to get across an alternative point of view: student achievement should not be attributed to media, but to the soundness of instructional methods, whether or not they incorporate media. A good review of earlier work in this direction, and a very cogent statement of current thinking, is presented in a recent paper by Richard E. Clark, "Reconsidering research on learning from media," which appeared in the winter, 1983, issue of Review of Education Research. Early in the article, Clark states:

> The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition. (p. 445)

The argument which Clark and others (e.g., Lumsdaine, 1963; Mielke, 1968; Glaser & Cooley, 1973; Levie & Dickey, 1973; Salomon & Clark, 1977) make is that the available evidence does not support the attribution to media of gains that have occurred in student performance. These authors have conducted extensive reviews of the literature on presumed benefits from media. They conclude, in general, that the research findings are confounded by rival, compelling hypotheses related to the uncontrolled effects of instructional method and novelty. As a result of this conclusion, Clark suggests,

> It seems reasonable to recommend, therefore, that researchers refrain from producing additional studies exploring the relationship between media and learning unless a novel theory is suggested. (p. 457)

What, then, can we study?

Aside from global considerations of "effectiveness," there are a great number of investigative areas that promise to provide researchers with interest and employment for the future. As the title of this presentation suggests, I think that most of these fall into "macro" or "micro" domains. This a not a novel distinction; in describing the studies which they reviewed, Jamison, Suppes, and Wells (1974) said, "The effectiveness of these media is examined from a reasonably macroscopic point of view; the psychology of pupil-teacher interaction or the 'content variables' of ITV [instructional television], to take two examples, are at a micro-level not considered" (p. 1).

For me, the principal distinction between the two is that macro-research focuses more on the implementation of technology and micro-research focuses more on learning (with technology).

Regarding, for example, use of CAI in schools, macro-research would investigate questions about computers and their implementation in schools; micro-research would examine the process of learning in situations where this technology is applied.

Under the category of macro-research, one might collect and analyze:

- information of a technical nature regarding computers;
- numbers and types of computers that are being used in various types of schools and educational programs; or
- data on the experiences of schools that have attempted to implement this technology.

In contrast, micro-research would concentrate on the specific use of computers for instruction; the focus would be on changes in learning and skill.

Macro-research on CAI

How does a new technology become established in education? First, the technology must be invented or developed. CAI is an instructional technology that was developed as a combination of two existing technologies: computers and programmed instruction. Development of a technology does not automatically lead to its acceptance or widespread use. As previously noted, CAI has been around for over 20 years; however, it has only become a "hot" item during the past few years. This sudden explosion of interest in CAI may be attributed to a number of factors:

- the economics of microcomputers;
- a general public mania for anything computerized;
- educators' perception of the potential value of CAI; and
- availability of computers acquired for other purposes--such as computer literacy--in the schools.

Macro-research on this development is becoming available. In terms of the technology itself, numerous technical and educational publications cover the hardware and software that is available, and provide reviews of the equipment. In fact, the amount of information available about the technology is, if nothing else, "extensive." It is patently impossible for anyone to keep up with this material. Fortunately, a number of organizations review materials in this field and provide information upon request (examples are microSIFT and EPIE/Consumers Union).

Another field of macro-research has been investigation of the extensiveness of CAI (and other computer) applications in the nation's schools. Two sources (Note 1) for this type of information are the reports produced by the Center for Social Organization of Schools, at Johns Hopkins University, and those produced by Market Data Retrieval in Westport, Connecticut. Both of these efforts rely on surveys (although MDR aims for universe coverage). Each of these surveys provides information on the numbers and types of microcomputers that are being used in schools, how (briefly) they are employed, and who is using them.

Finally, in the area of implementation, there is a need for more research. Schools are social institutions. To greater and lesser degrees, school systems are characterized by centralized systems of authority, by the presence and articulation of various service delivery mechanisms and providers. Schools are also part of communities and branches of state government. Schools are political.

The introduction of technological innovation in such a setting suggests a process of interactions: the existing school environment will affect the technology and, in turn, the technology will (if accepted) affect the educational system. Therefore, a principal focus of investigation on the implementation of technologies--particularly flexible media like computers in education--should be on organizational factors. Who is involved in the introduction of the technology? What roles do they play and what procedures and steps do they pursue? How is the use of the technology affected by the players and, in turn, what changes occur in the schools systems in association with the innovation.

Some of these issues have been examined individually by educational researchers. Burello, Tracy, and Glassman (1983) surveyed the use of electronic technology in special education management; they examined the categories of special education personnel responsible for computer management. Hoover and Gould (1983) cited the importance of the "microcomputer coordinator" in the implementation of this technology in schools. Zuckerman (1983) identified eight levels of computer use by teachers and linked them to needs for improved teacher training.

On the whole, however, there has been relatively little empirical study of implementation issues. Special Education Programs (SEP/OSERS) in the U.S. Department of Education is very interested in this area. On their initiative, a two-year study was conducted on "Microcomputers in the schools: Implementation in special education" (SRA Technologies and Cosmos Corporation, 1983). We examined the processes and people involved in introducing this technology in 12 school districts where microcomputers have been used in special education. Our findings are readily aviailable (Note 2) so I will not concentrate on them here. Instead, I would like to say a few words about the methodology which we employed for this macro-research.

The study utilized a case study approach. By and large, educational researchers have relied heavily upon experimental or quasi-experimental designs or, in larger studies, survey methods. Case studies have had a more limited use; although, recently they are receiving increased attention.

The microcomputer study was my first direct experience with a case study approach. I must admit that my own previous biases for more "statistical" methods led me initially to question the utility of the technique. I can report now, hwoever, that I am firmly convinced that this method was extremely useful in this investigation and I advocate that other researchers give it serious consideration for similar research efforts.

To begin with, there are a number of elements present in this domain (computers in education) that mitigate strongly agianst the application of traditional empirical methods:

1. The populations of interest are unknown (except in the very broadest sense). This represents a very fundamental problem for anyone who plans to attempt surveys related to computer applications in schools. There is very limited universe information available about who is doing what; and the rapid growth (and change) in the nature of applications produces an insurmountable time-lag between definition of a sample, measurement of its traits, and inference/generalization--the population has moved.

2. The variety of applications and participants is enormous. This is the problem of incomparability. I can't think of a research area where this problem is more severe than in the study of CAI in special education. The "experimental apparatus" varies incredibly across settings, in terms of the particular hardware and sofrtware that is used. Additionally, the nature (to replace or augment instruction?) and the extent (every day or once a month?) of the applications; the role, knowledge, and participation of the teachers and adminstrators; the nature and severity of the handicaps of the students--all of these components vary markedly, from study to study, and across different education programs. It is difficult to produce measures of anything in this domain that will have broad meaning, precision, or replicability. (An example in point are the estimators of effect size from the meta-analyses described earlier. Are they representative samples of a singular effect? Can studies with different types of subjects, software, methods, etc., really be compared?)

Alternatively, the case study approach does not attempt to quantify anything. Instead, it proposes to examine the relationships among different elements in an environment and draw conclusions in reference to a priori expectations. I stress the a priori element because many researchers tend to think that case studies are, at best, small surveys or, at least, an example of "data snooping." Case study methodology, as it is now developed (e.g., Yin, 1981a), is a serious and rigorous investigative approach. It is just as important in case studies to develop and specify initial hypotheses regarding the subjects of interest, as it is in more traditional research approaches. We did that in our study and our predictions were based on previous research findings where they were available.

A chief difference between case study methods and stochastic approaches is that in a survey or experiment the data elements are assumed to represent scores from a population. In the case study approach, each case is assumed to represent a separate "experiment." The hypothesis being tested is of the form, "given *a* then *b*", or, "given *a* and *b* then *c*." There is no attempt to develop a point estimate (statistic).

For example, one of the issues in our research related to attempts to combine *both* administrative and instructional applications on microcomputers. Previous research (e.g., Yin, 1981b) had found serious problems in this area -- with mainframe computers systems: administrative uses tended to receive higher priority and "squeezed" instructional users off the system (or limited their access). A hypothesis, therefore, was that this negative effect would also occur with microcomputer use.

To test the hypothesis, we purposely selected some school districts where administrative and instructional applications were combined on the same system of microcomputers. Conversely, we also selected schools where only one type of application occurred. In brief, we found that the negative relationship did *not* hold. Administrative and instructional applications could coexist with microcomputers.

Further, the case study methodology permitted us to examine and subsequently report in detail many of the features and procedures that users felt contributed to the positive outcome. A principal explanation for the success of both types of applications was the nature of microcomputer technology. In a large, centralized (such as a mainframe or minicomputer) system, the computer has built-in limitations on growth. With greater demands from users, the technology reaches a top limit on the numbers of users and applications that can be handled. It becomes necessary to place restrictive priorities and, unfortunately, the instructional users tend to suffer the most.

Not so with microcomputers -- the system can grow incrementally. As use expands, additional microcomputer units can be acquired at a gradual and economic pace, to more equitably satisfy the needs of users: administrators and teachers.

This is just one example from our study, but it demonstrates the advantages of the case study approach, especially in an area where parameters are not well established and individual variation is large. Based upon previous research (or informed reasoning), fairly specific hypotheses can be establihed and tested. Another advantage of the approooach is that -- whether or not the initial hypotheses are supported -- the case study methodology produces a great amount of additional information that can be instructive and guide researchers into future, promising areas of investigation. This is a result of the emphasis in case studies on extensive interviewing, observation, and documentation. The method also allows for the enexpected to occur and provides opportunities to obtain a wide range of potentially valuable information.

To sum up this section on macro-research, I think there are three principal areas currently needing investigation and there are a variety of useful approaches that can be applied to each:

1. Technology, per se--review or testing of hardware and software;

2. Gross characteristics of the penetration of technology into schools--surveys and censuses of units, users, and applications; and

3. Implementation issues--case study methods represent a promising approach that avoids some of the problems inherent in stochastic techniques.

Now I would like to turn to more "micro" elements of needed research and, in doing so, focus on issues of "effectiveness" related to using CAI in special education.

Micro-research on education

As earlier remarks indicated, I don't believe it is appropriate to attempt to measure some sort of global "effectiveness" of CAI. In fact, at this point I'd say that handicapped children may represent, probably, the least applicable population for global measurement of anything. I think this viewpoint in very much in keeping with the general principle that we in special education have espoused for years--respect for the individual nature and needs of each child.

Nevertheless, I'll also admit that I'm an unabashed advocate and propagandist for the use of CAI in special education. Basically, my perception is that the microcomputer is a very powerful instructional medium. However, I don't think it is as easy to use (appropriately) as some people contend; effective educational use of the technology requires two things:

1. some understanding of microcomputers; and

2. understanding of educational principles.

Consequently, I believe that research on CAI should focus on the the educational use of microcomputers and should be designed to get useful information across to those who plan to use the technology: special educaton administrators and special education teachers. In the remaining minutes of this presentation, I'm going to tell you how I think that should be done. But first, let me share one final anecdote with you.

From 1973 to 1976, I participated in the design and development of a "solid-state, digital-logical, experimental learning laboratory" at Rutgers University. During that period, we invested over $8,000 and countless man-hours in construction of an elaborate electronic control system for educational experiments. We thought we were building a very high-tech, state-of-the-art research environment -- with numerous electronic switches, "mac" panels, peripheral devices, paper-tape punches and readers, LED displays, etc., etc., etc. This laboratory would permit us to conduct a wide variety of controlled learning studies with human subjects. We could vary the presentation of stimuli, record responses and latencies, and automate data production. It would be magnificent.

About the time we were finishing our laboratory, microcomputers were introduced. We checked them out. We gulped. We said, "(expletive deleted), we could have had a TRS-80!" (For all the money we had spent, we could have had a whole bunch of TRS-80's.)

The point is--a microcomputer is a piece of equipment that can do just about everything that all the preceding experimental apparati and teaching machines attempted to do. Microcomputers today, with their larger memories, increased processing speed, and extensive peripherals, can control, monitor, and deliver a limitless range of instructional information. In effect, microcomputers can convert our schools into one large, national "solid-state, digital-logical, experimental learning laboratory."

The question remains, however, is it going to work? Will CAI improve the quality of instruction in special education? Those are the questions that research must address.

Micro-research: pedagogy and application

Pedagogy is the art and science of teaching. Educational research (including educational psychology) is different from some other research (such as "pure" psychology) because its objective is pedagogy--the application of the principles of learning to the art of instruction.

The subject of concern here is CAI. What research can or should be done? First of all, I think we have to turn aside from amorphous investigation of the "effectiveness of CAI" and become much more focused on the real topic of interest: learning. That topic can be subdivided into two research components: (1) learning in general, and (2) individualized learning for a specific child (the special education focus).

Regarding learning "in general," educational researchers have a terrific opportunity. The microcomputer is a remarkable research tool. The widespread availability of microcomputers in schools means that researchers can now obtain educational data on a scale not heretofore imagined. To the degree that software is designed (or modified) to record indicators (scores, correct and incorrect responses, latencies, etc.) of the progress of learning, this technology will provide valuable information that can readily be collected and analyzed.

Turning, however, to the more specific study of CAI, researchers must understand that a particular CAI program (CAI software is often called "courseware") is typically a composite of numerous, independent educational strategies. Even primitive "drill-and-practice" programs differ markedly from one another, in terms of:

- the content that is presented
- the format of the presentation;
- the type of response that is required;
- the nature and schedule of reinforcers;
- the criteria for success;
- the degree of individualization (i.e., branching) for different students who use it; and
- the "bells and whistles" built into commercial courseware.

Most of the popular, commercial courseware products vary a good deal in terms of these components. Simple comparisons between the effects of different courseware products have a limited value. It may be interesting to know that one "stew" is better than another, but such a discrimination has no explanatory power.

Frankly, teachers and administrators currently have a strong interest in such comparative analyses. In the short run, these comparison studies (technical/educational journals and magazines regualarly provide such reviews) may have some usefulness. At the least, they may prevent some teachers from purchasing some of the "dogware" that is still being marketed.

Ultimately, however, more controlled analysis of CAI software is mandatory. Many authors (e.g., Cohen, 1983; Jay, 1983; Steffin, 1983) have identified particular features of CAI software that should be considered. Much of this writing has, however, been subjective; sound educational principles are reflected in the opinions of the authors but the relative importance of the chosen features has not been extensively tested.

The goal of this research would be to provide an understanding of the elements of CAI--not just software, but also procedures, student and teacher factors, etc.--that contibute to appropriate and effective use of CAI. It then becomes the responsibility of policy-makers, teacher-trainers, and educational administrators to use this information and to disseminate it.

Micro-research in the classroom

The classroom--special education or otherwise--is where the ultimate value of CAI will be determined. The classroom is the new "learning laboratory." This fact requires a reconsideration of the role of the teacher. In brief, the teacher is now also an educational researcher. This is not solely a result of the introduction of microcomputers. In special education, we've been gradually moving in this direction for years. A key factor has been our growing investment in the concept of "individualized instruction," a process that requires (1) student assessment and (2) prescriptive teaching.

We believe so strongly in the value of this process that we've, more-or-less, attempted to legislate it into existence, through the IEP provisions of P.L. 94-142. Unfortunately, legislation does not automaticly transform an educational philosophy into a classroom reality. I'm sure that many of you here will agree with me that much of the activity related to IEP's over the past decade has often been more a "paper chase" than an actual transformation in instructional procedure.

Now, however, a tool that has its origins in the experimental learning laboratory has been deposited in the classroom--a tool that truly can be a "teaching machine." But it is not a "teacher." A human being is still required to determine how the microcomputer will be used and, particularly in special education, exactly how CAI will (or will not) be individually presented to each student.

My opinion is that the teacher cannot do that without some understanding of the technology and a *better* understanding of the principles of learning. In the school districts that we visited for the case studies, we were generally very pleased with the findings on most of the organizational issues. However, we were somewhat disappointed in our observation of actual CAI applications in special education classrooms. The typical application used "drill-and-practice" exercises or "educational games." Rarely was the CAI linked directly with students' individualized educational goals and objectives. Teachers often reported that they used the microcomputer as a "motivator," or to free up their own time to work individually with a student, while other students were using the computers. These are legitimate uses of the technology, but they certainly don't represent the sort of potentially powerful applications that have been envisioned by education theorists.

In truth, many of these teachers, especially those who had not requested but had been *given* their microcomputers, reported that they were at a loss as to exactly what to do with the units. They often asked us (members of the case study research teams) if we knew of any "good" software that they could get. They clearly were not in control of the technology and they viewed it as a "black box" that could, perhaps, solve their needs if only they had better software.

If it is true that all of the benefits attributed to CAI can actually be credited to the uncontrolled effects of instructional method and novelty (as Clark, 1983, claims), then we may have a problem on our hands. The novelty effect is going to wear off soon. We will have to rely on instructional methodology. That means that teachers will have to become much more knowledgeable and creative about their utilization of this technology, particularly if they are to tailor the applications to meet the needs of individual students.

Along these lines, I wonder if it is wise to even consider CAI without also considering computer-managed instruction (CMI). This is the component that truly transforms the teacher into a researcher. The computer not only delivers the instruction, but also provides the teacher with a mechanism for monitoring the student's progress and modifying the CAI.

In fact, this is the area where I think most research needs to be done: how do we prepare special education teachers to act as researchers in the classroom? This ultimate focus actually ties macro and microresearch back into one unified research thrust. On one level (micro), it is critically important that we identify all the essential parameters describing the successful use of CAI. For special education this is a complex undertaking because in must reflect an understanding of the great range of individual differences that exist in the populations that we serve. It will, therefore, incorporate further investigation of the instructional strategies that can be effectively utilized to improve learning under differing circumstances. This investigation will also explore the ways that microcomputer-based instruction can replicate effective learning strategies.

At the macro level, we must then evaluate the methods we use to get this information across to special education teachers. I suspect we will find that it is not very difficult to get most teachers to understand what is essential about microcomputers. I anticipate that the greater challenge will be to provide teachers with a better understanding of the principles of learning.

Reference Notes

1. A series of reports on "School Uses of Microcomputers" is available from Dr. Henry Jay Becker, Project Director, Center for Social Organization of Schools, The Johns Hopkins University, Baltimore, Maryland, 21218.

   Reports on "Microcomputers in the Schools" are available from Market Data Retrieval, Inc., of Westport, Conn., 06880.

2. A description of the reports, and procedures for acquiring them is available from Ms. Laura S. Clark, Dissemination Specialist, SRA Technologies, 901 S. Highland St., Arlington, Virginia, 22204. (Many of the reports are also available from the Regional Resource Centers and from CEC;Clearinghouse on Handicapped and Gifted Children, Reston, Virginia, 22091.)

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AN OVERVIEW OF INTELLIGENT CAI SYSTEMS

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An Overview of Intelligent CAI Systems

Abstract

Artificial intelligence (AI) is an interdisciplinary field of computer science, psychology, and linguistics which has been actively evolving over the past 25 years. AI is defined as the attempt to get computers to perform tasks that if performed by a human being, intelligence would be required to accomplish the task. While most AI work has historically been restricted to the research laboratories, recent advances have afforded the opportunity to apply principles of artificial intelligence in several areas of application, including vision processing, speech understanding and generation, robotics, and expert problem-solving systems. In addition to these areas, AI has been successfully applied in instructional delivery systems as well, referred to as intelligent tutoring systems, or intelligent computer-assisted instruction (ICAI).

ICAI systems separate the major components of instructional systems in a way which allows both the student and the program a flexibility in the learning environment more closely resembling what actually occurs when a student and teacher sit down one-on-one and attempt to teach and learn together. These major instructional components are the content to be taught, a method for teaching the content, and an understanding of the student who is being taught. These components are the same as those which any teacher must address. ICAI systems provide a framework for the separation and subsequent interaction of each of these components, providing both the student and "teacher" multiple paths through both content and instructional strategy, to achieve the intended learning outcome. At any stage in this process, either student or teacher can ask or answer a question, thus allowing a mixed-initiative dialogue in a natural language environment.

Thus, ICAI systems provide a modular structure for instructional delivery, and provide two-way communication between student and teacher through a mixed-initiative dialogue. These systems typically have three major components: (1) an expertise, or problem-solving model to represent the domain knowledge to be taught; (2) a tutoring, or expert teaching model which manifests the instructional strategy to be used; and (3) a model of the student, including individual student characteristics as well as how much they do or do not know about the content. These three models then interact resulting in a fluid, active learning environment for the student.

It should be noted that this description of the purpose and structure of ICAI systems is somewhat idealized. There are no systems yet in existence which have complete and powerful models for each of these three components, and the natural language environments in most of these systems are somewhat restrictive. However, the technology surrounding ICAI systems has evolved to a point where many of these models have been implemented at least in part. Much of this work has developed in parallel with the human factors work on "man-machine dialogues", as well as in the recent advent of authoring systems.

Introduction

In the last few years, artificial intelligence (AI) has emerged from the research labs to become a central component in many areas of high technology development: computer vision, speech generation, robotics and expert problem solving systems are but a few of the many ways in which artificial intelligence has been applied to solving problems in high technology areas. Artificial intelligence is defined as the attempt to get computers to perform tasks that if performed by a human being, it would generally be thought to require intelligence to perform the task.

In addition to the application areas mentioned above, AI has been applied in the field of education as well, with the result often being referred to as intelligent tutoring systems, or intelligent computer-assisted instruction (ICAI). ICAI systems have taken on many forms, but essentially they have separated the major components of instructional systems in a way which allows both the student and the program a flexibility in the learning environment which more closely resembles what actually occurs when student and teacher sit down one-on-one and attempt to teach and learn together. This paper briefly reviews the components of artificial intelligence, the structure of ICAI systems, some examples of such systems, and ends with a review of their relative strengths and weaknesses.

Principles of Artificial Intelligence

Artificial intelligence has recently been receiving a great deal of attention in the popular press, indicating that in many ways it has evolved from its research and theory status of the past two and a half decades to become a viable tool in today's complex, technological world. As an evolving, interactive discipline it is difficult to place an exact definition and boundary on the field. A common definition used is:

> Artificial Intelligence: the attempt to have computers perform tasks that, if performed by human beings, would generally be considered to require intelligence to perform those tasks.

Inherent in this definition are the three basic building blocks of AI systems: (1) the understanding of human behavior, (2) the ability to store, search and use the required knowledge, and (3) the ability to communicate with a human user. The disciplines underlying these components are cognitive psychology, computer science, and linguistics.

Much of the contribution from psychology has been in the realm of understanding human problem solving behavior, as well as the work in memory modeling. The method of protocol anaylsis has been used extensively in trying to understand how experts solve problems, and the distinction between expert and novice problem solvers plays an important role in much of the ICAI work going on today. The result of this type of work lends itself to an explicit description of the information required to solve certain types of problems, as well as procedures for solving the problems themselves.

Once this information is known it is encoded in an appropriate knowledge base structure. These structures are generally some type of semantic network, and work in this area has evolved both in the fields of computer science and linguistics. These knowledge structures include two basic types of knowledge: declarative and procedural. In educational terms, declarative knowledge would include facts, concepts, and principles, whereas procedural knowledge would include rules, procedures, and problem solving strategies. Once this knowledge base is established and a problem is defined, the task is then to use the procedural knowledge as a guide to search through the knowledge base for both a solution path and, ultimately, a solution. In a small knowledge base it is fairly easy to search all possible paths to find either a solution or the best solution. As the knowledge base grows, the time for a complete search grows exponentially; accordingly, the field of computer science has developed a whole range of techniques to address the efficient search of knowledge bases.

Finally, such a system must interact with a human user, both for the initial input of information and for the final explanation of the final solution. Many AI systems have a human interface that provides a mixed initiative, natural language environment. Natural language here refers to a common spoken language such as English, german or french. In these systems, the user is able to type in statements or questions in a natural language, and the computer will be able to understand what is being communicated. The term "mixed initiative" refers to the ability of both the user and the computerto ask and answer questions of each other. In practice, these natural language systems are not as flexible as human speech is, and are generally constrained by a restricted vocabulary and syntax rules.

Three Components of ICAI Systems

ICAI systems apply principles of artificial intelligence in the representation of domain knowledge, natural language dialogues, and methods of inferences. The operational functions of an ICAI system are determined by three main components or modules. These modules represent the three main components of any instructional system, namely the content to be taught, the inherent teaching or instructional strategy, and a mechanism for understanding what the student does and does not know. In ICAI systems these modules are referred to as the expertise, teaching, and student modules (Clancey, Barnett, & Cohen, 1982). Due to the size and complexity of most ICAI programs, not all of the three components are fully developed in every system. Most systems focus on the development of a single part of what would constitute a fully usable system (Clancey, 1979). The ultimate goal of ICAI, however, is to have a system which has powerful models in each of these three components, and to have these components work together to produce the most effective learning environment possible. Each of these modules is elaborated on below.

1. Expertise module. An expertise, or problem solving module consists of the domain knowledge that the system is imparting to the student. This knowledge includes both the content to be taught and how to use that knowledge to solve related problems. The latter of these is referred to as procedural knowledge, and represents the procedures used by "experts" in solving problems of this type. The expertise module is charged with the task of

generating questions and evaluating the correctness of a student's problem solution. The knowledge of subject matter may be represented by one or more of the following methods: (a) semantic nets in a huge, static database that incorporate all the facts to be taught; (b) procedural experts that correspond to subskills that a student must learn in order to acquire the complete skill being taught; (c) production rules that are used to construct modular representations of skills and problem solving methods; and (d) multiple representations that combine the semantic nets of facts and the procedures of functional behaviors of the facts (Clancey, et al., 1982).

2. Student module. The student module is a method of representing the student's understanding of the material to be taught. This module is used to make hypotheses about the student's misconceptions and suboptimal performance strategies so that the system can point them out, indicate why they are wrong, and suggest corrections. Modeling the student knowledge uses (a) simple pattern recognition applied to the student's response history and (b) flags in the subject-matter semantic net (or the rule base) representing areas that the student has mastered. Major information sources for maintaining the student module are (a) student problem solving behavior (implicit), (b) direct questions asked of the student (explicit), (c) assumptions based on the student's experience (historical), and (d) assumptions based on some measure of the difficulty of the subject material (structural).

3. Tutoring module. A tutoring module is a set of specifications of how the system should present materials to the student. The tutoring module integrates knowledge about natural language dialogues, teaching methods, and subject materials. This module communicates with the student in selecting problems for him or her to solve, monitoring and criticizing his or her performance, providing assistance upon request, and selecting remedial materials. The strategy in the tutoring module is based on one of the following methods: (a) a diagnostic or debugging approach in which the system debugs the student's misunderstanding by posing tasks and evaluating his or her response; (b) the Socratic method which involves questioning the student in a way that will encourage him or her to reason about what he or she knows and thereby modify his or her conceptions; or (c) a coaching method in which the student is engaged in some activity like a computer game to encourage skill acquisition and general problem solving ability. (See Clancey, et al., 1982, for a comprehensive description of the above three components).

Development of ICAI Systems

Carbonell's (1970) SCHOLAR system for teaching South American geography served as an impetus for the development of ICAI systems. SCHOLAR utilizes a complex but well-defined information structure in the form of a network of facts, concepts, and procedures as a data base. The elements of this network are units of information defining words and events in the form of multi-level tree lists. In SCHOLAR, the Socratic style of tutoring dialogue is used. The system first attempts to diagnose the student's misconceptions and then presents materials that will force the student to see his or her own error (Collins, Warnock, &

Passafiume, 1975). SCHOLAR's inference strategies, for answering student questions and evaluating student answers, are independent of the content of the semantic net and applicable in different domains.

SCHOLAR is extended by the WHY program (Stevens & Collins, 1977). WHY tutors students in the causes of rainfall, a complex geophysical process that is a function of many interrelated factors. WHY implements the Socratic tutorial heuristics that describe the global strategies used by human tutors to guide the dialogue.

O'Shea developed a system at the Univeristy of Leeds in England referred to as a self-improving quadratic tutor (O'Shea, 1979). This system has two principle components: one is an adaptive teaching program which is expressed in a set of production rules, and the other is the self-improving component which makes experimental changes in the production rules of the teaching program. The system is designed to conduct experiments on the teaching strategy by altering the production rules. Data is kept on the effectiveness of the changes, and those modifications which result in improved student performance are incorporated into the set of production rules. This work is particularly interesting in its adaptive nature and has not been investigated to any great extent. Another self-adapting ICAI system of note is Kimball's self-improving tutor for symbolic integration. A description of this system can be found in Kimball (1973) and Sleeman and Brown (1982).

Brown, Burton, and Bell (1975) developed the SOPHIE system which is an attempt to create a "reactive" learning environment in which the student acquires problem solving skills by trying out his or her own ideas rather than by receiving instruction from the system. SOPHIE incorporates a model of the knowledge domain along with heuristic strategies for answering a student's questions, provides critiques of his or her current learning paths, and generates alternative paths (Brown & Burton, 1978a). SOPHIE allows the student to have a one-to-one relationship with a computer-based expert who helps the student come up with his or her own ideas, experiment these ideas, and, when necessary, debug them.

The principles of SOPHIE has been applied for constructing a diagnostic model (BUGGY) in learning basic mathematical problem solving skills (Brown & Burton, 1978b) and for developing a computer-coaching model in a discovery learning environment (Burton & Brown, 1979). The BUGGY program provides a mechanism for explaining why a student is making an arithmatic mistake, as opposed to simply identifying the mistake. BUGGY allows teachers to practice diagnosing the underlying causes of students' errors by presenting examples of systematic incorrect behaivor.

The coaching model is used to identify diagnostic strategies required to infer a student's misunderstandings from the observed behaviors. It is also used as a tutoring strategy for directing the tutor to say the right thing at the right time (Burton & Brown, 1979). WEST is a coaching program designed to teach the appropriate manipulation of arithmatic expressions in a computer gaming environment (Burton & Brown, 1979). Another coaching program is Goldstein and Carr's (1977) WUMPUS. WUMPUS is designed to foster the student's (game player's) ability to make proper logical and probabilistic inferences from the given information.

Clancey's (1979) GUIDON, another program for teaching diagnostic (medical) problem-solving, is different from other ICAI programs in terms of the mixed-initiative dialogue. GUIDON uses the prolonged and structured teaching interactions that go beyond responding to the student's last move (as in WEST and WUMPUS) and repetitive questioning and answering (as in SCHOLAR and WHY). In GUIDON, the tutoring rules are organized into discourse procedures and the subject materials (medical diagnostic rules) are hierarchically grouped into a separate system, called MYCIN. MYCIN is a computer-based consultation system for the diagnosis and therapy of infectious diseases.

Suppes and his associates also applied artificial intelligence techniques in the development of a proof checker (EXCHECK) capable of understanding the validity of a student's mathematical proof (Blaine and Smith, 1977). EXCHECK has no student module, but its inference procedures in the expertise module allow it to make assumptions about a student's reasoning and track his solutions, thus providing a "reactive environment" similar to that of SOPHIE. Clancey, et al. (1982) thoroughly reviewed eight representative ICAI systems: SCHOLAR, WHY, SOPHIE, WEST, WUMPUS, GUIDON, BUGGY, and EXCHECK.

Another application of artificial intelligence techniques for computer-based education is to create a new educational environment through full control of the learning experience by the student (Papert, 1980). Papert's LOGO is a special language designed for this purpose. Taylor (1980) calls this approach "use of computer as a tutee" to distinguish it from other approaches in which the computer is used as a "tutor." However, this approach is not considered as an ICAI system in this paper because of its different educational perspective and operational procedures.

ICAI Systems: Potentials and Limitations

Intelligent CAI systems represent the state-of-the-art in what "could be" in computer-based instruction (CBI). The structure of these systems offers a model for CBI systems of the future, and as such, they they have the potential of offering fertile research opportunities in exploring how students learn and how we might be more effective in teaching them. At the same time, the rhetoric surrounding this work often leaves the reader with the impression that ICAI systems that can intelligently teach any subject on any terminal are just around the corner, and this is clearly not the case. In some limited circumstances, ICAI systems can be used to deliver instruction today; the biggest potential impact, however, is in their potential for offering insights into the various components in the teahing-learning process. Some of the more prominent advantages and disadvantages of these systems and the work on which they are built is offered below.

Advantages and Potentials of ICAI Systems

Instructional research in the classroom has a great many limitations, but probably the most significant of these is the difficulty in isolating instructional strategies that can be replicated with other teachers, different students, over various subject areas. Traditional CBI has offered a research environment which can overcome some of these obstacles, but even there the distinction between content, teaching strategy, and student characteristics often becomes blurred. Perhaps the biggest benefit that ICAI systems have to offer is the ability to unambigously isolate each of the four components of ICAI systems: (1) student characteristics (through the student model), (2) the instructional strategy used (via the tutoring module), (3) the subject matter to be taught (through the knowledge representation system), and (4) the nature of communication between student and teacher (as manifested in the natural lanaguge system). Each of these four areas represents major efforts being conducted in traditional instructional and classroom research. More cooperation between the AI and educational communities might offer both sides some benefits.

A second potential offered by ICAI systems is concerned with a major shift now occuring in the CBI field. Namely, the change from programming languages to authoring systems. In the programming language environment, the author writes lines of code which intermix information about the content, the student, and the intructional strategy being used. The authoring language environment typically isolates these componentsand offers the author higher level alternatives in manipulating the various components. The similarities between the structure of authoring systems and ICAI systems is probably not coincidental, and as authoring systems continue to make headway in the CBI field, work in ICAI can offer valuable insights into alternative ways in which authoring systems might be built.

A third advantage of ICAI comes as a spin-off in investigating how people learn. An excellent example of this is in the work accomplished in building the BUGGY system. Historically, teachers have generally believed that most of the errors students commit in arithmetic were random aberrations of the correct method of solution. While there was always the belief that some systematic errors probably did occur, the huge number of possible error patterns made the task virtually impossible for any classroom teacher. In the development of BUGGY, the researchers considered all possible student solution paths, both correct and incorrect, for solving arithmetic problems. The correct path was then compared to the path the student actually took, and they found that nealry 80% of all student errors were systematic in nature. The result of this is that carefully choosing example items for students to solve, evidence can be built up which show the misconceptions which students have. As a result, instruction can be specifically remedial for correcting a student's misconception, or "bug" as it is called. The larger benefit here is that through complex, probabilistic reasoning (often called fuzzy reasoning in AI) many other relationships in the teaching/learning process may also be made more clear to us.

The fourth and final benefit of ICAI systems presented here is in the areas in which they can be implemented today. The best example of this is the GUIDON system, and it is happening in conjunction with an area of AI known as expert systems. Expert systems are an application of AI techniques which simulate the problem solving of experts in such areas as chemical analysis, medical diagnosis, and computer fault diagnosis. Given the relevant information, these systems can often solve problems as effectively as experts in the field. In addition, once the problem is solved, they can explain the reasoning they used to arrive at their conclusion. This has prompted many of the AI researchers in expert systems to proclaim that it is "just a small step to take this ability to explain and make it into a teaching system". Well, the step is a large one, but some significant strides have been made, and those made with the GUIDON systemare exemplary.

GUIDON is an expert teaching system used in conjunction with the expert problem solving system called MYCIN, a medical program for diagnosing myocardial infections. What really makes this work significant, however, is in the evolution of mYCIN and other expert problem solving systems like it. After MYCIN was proven to be effective in diagnosing myocardial infections, the researchers investigated whether the problem solving logic used in MYCIN might not also be useful in solving in other kinds of similar problems. The medical knowldge was extracted from the system leaving an empty version of MYCIN's problem solving logic, called EMYCIN (for essential, or empty MYCIN). Other content domains were then entered into EMYCIN and it was found that (with certian restrictions) EMYCIN was just as effective in solving these new problems. Even more impressive is the fact the GUIDON was found to be a useful teaching system with these new content areas as well. With the advent of these "generic" expert systems that only need to have new content domains entered,the 10 to 50 person-years generally associated with expert systems development has dropped to 1 to 3 years, and their use has correspondingly increased. This will likely be the most productive area of ICAI development throughout the next decade.

Problems and Limitations of ICAI Systems

In considering the state-of-the-art of artificial intelligence as it relates to CBI, it is important to keep in mind a distinction between "what might be" and "what is". Many of the write-ups in the literature discuss a prototype system, the problems encountered in that system, and the recommendations for how those problems might be solved. This is very different from describing a system that has actually solved those problems. Another misleading notion can be found in the names given to many of the components of ICAI systems. The expert teaching models, for instance, are considerably less than models of expert teaching; they are usually just a set of rules used for teaching the content in question. Whether they are the best models or expert models is another question.

However, most of the problems and limitations inherent in existing ICAI systems will most likely be resolved at some time in the future. The key question is not if, but when will these problems be resolved. Before trying to answer this question, we offer a brief review of some of the more prominent limitations of current ICAI systems.

One of the most prevalent limitations in ICAI systems is in the nature of the student-computer dialogues. While most ICAI systems recommend a natural language dialogue between student and computer, most existing systems are considerably more narrow than most natural environments. Understanding natural language is an extremely complex task, and one which is being heavily researched in the AI community. In the meantime, existing systems must require the students to use a subset of the language, often with some syntax rules that must also be followed. Of course, when the computer does not understand a student's utterance, a parroting response such as "What do you mean by...." can always be issued recursively until an understandable response is provided. However, until the natural language problem is solved, this will be a limiting factor in the use and development of ICAI systems.

A second limitation can be found in the inherent assumption that we can understand what a student knows by comparing the student model to the corresponding expertise model. The problem here is that we do not know very much about the differences in how people reason, and the expertise model may not be appropriate for all students; this may be even more true when considering the cognitive developmental stages that pre-adult students must go through. However, while this is a limitation for existing systems, it can also be seen as a research opportunity in the development of future systems.

A third limitation is in the extreme labor-intensive nature of ICAI systems development. The amount of time and effort required to build an ICAI system which teaches even a small amount of content is still enormous, often on the order of many person-years. While generic expert systems hold a potential for signicantly reducing this development time, the current state-of-the-art almost precludes any ICAI development except for research purposes.

A fourth limitation has been in the content domains chosen for implementation. Most ICAI systems have been restricted to the highly structured content areas like mathematics, electronics, and games. While Carbonell's geography lesson shows that this need not be the case, the wide applicability of ICAI systems and models needs to be verified in other content domains as well.

A final issue which will limit the near-term usage of ICAI systems is in the inherent hardware and software requirements. Most ICAI systems require very powerful LISP processing machines. There are some desktop computers available now that will handle these requirements very well; however, their cost is generally prohibitive for the individual consumer (50K - 100K). In addition, current AI research is moving towards machines which can perform parallel processing, and this will probably increase the hardware costs, at least in the foreseeable future. However, computer hardware costs have a long-standing tradition of dropping dramatically, and accordingly, this problem may only be a temporary one.

Summary

In summary, intelligent computer-assisted instruction is the attempt to provide a natural (computer-based) environment for the student which simulates what occurs between a student and tutor in a one-on-one situation. ICAI systems are modular in nature, with the common components being a student module, a tutoring module, and an expertise or domain knowledge module. Each of these modules interacts with the others, and the result is communicated to the student though a natural language, mixed initiative dialogue.

While ICAI systems represent the state-of-the-art in computer-based instruction, their impact on instructional delivery is not likely to be widespread in the near-term. They offer an ideal laboratory environment for investigating many of the components in any instructional system, and can also be used as structural models for the recent advent in authoring systems. They have also provided some insights in how people learn by providing an immediate, powerful analysis of student response patterns. While these advantages are promising, there are limts to be overcome as well. The natural language environments that currently exist are fairly rigid, and work in natural language understanding will have to be furthered before this problem can be overcome. In addition, the stuent and teaching models rely heavily on models of learning which are still being developed. Other limiting factors include the huge amounts of development time required to build an ICAI system, the costly hardware requirements, and the narrow range of content domains for which ICAI systems have been built.

A common question asked in this context is: When will ICAI systems become readily available in the marketplace? Unfortunately, this is not a simple question to answer. Clealry, we have already seen some influence from the work being done in ICAI in the development of authoring systems, if not directly, at least in the similarity of their structures. With the current proliferation in the use of expert systems in business, industry and government, we may see actual ICAI systems like GUIDON implemented on a widespread scale in the next 5 to 10 years. Much of the work in natural language might also be implementable in non-AI environments in ways which could faciliate a student's ability to ask questions of his or her computer tutor. But given the work that remains to be done, the small amount of work that is occuring in ICAI, and the long-term development time that is required in many of these systems, the authors' opinion is that widespread use of true ICAI systems will undoubtedly occur, but not for 15 to 20 years.

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EXPERT SYSTEMS: THEIR POTENTIAL ROLES WITHIN EDUCATION

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Introduction

Artificial Intelligence has existed as a distinct field of computer science for over two decades but only recently has received an enormous amount of public attention. What exactly is meant by the term "artificial intelligence"? There is no universally accepted definition, but one which captures the flavour of the field is presented in (Rich, 1983, p1): "Artificial Intelligence (AI) is the study of how to make computers do things at which, at the moment, people are better."

Within the field of AI, there are several major research areas such as knowledge representation, game playing, problem solving (both general and expert), natural language understanding, machine learning, vision and speech. Research advances in all of these areas could have a profound impact within the field of education, which is certainly an appropriate application area.

For the moment, however, we will restrict our attention to one particular area of AI -- the development of expert systems. An *expert system* is an automated consulting system designed to provide the user with expert advice within a particular subject area. The system embodies knowledge of a particular application area combined with inference mechanisms which enable the program to employ this knowledge in problem-solving situations (Hayes-Roth, Waterman & Lenat, 1983). A great deal of recent research and attention in AI has focussed upon expert systems; for example, see (Barr & Feigenbaum, 1982; Hayes-Roth, Waterman & Lenat, 1983; Michie, 1979) and the references therein.

Expert Systems

An expert system applies the knowledge encoded in its software to aid or advise the user. In order to do this, a substantial amount of information concerning the techniques and procedures employed within the given domain must be encoded. This data, which represents human experts' knowledge, is employed by the system to advise the less experienced user. For example, an expert medical system might guide an inexperienced intern by asking appropriate questions. The intern would obtain and enter the answers into the computer until sufficient data had been collected for a diagnosis. For a field as large and varied as medicine, the scheme is complex.

Expert systems have been developed for general use in a variety of areas, with many others currently being designed and developed. One of the better-known is DENDRAL, which determines the chemical structure of complex organic molecules (Buchanan & Feigenbaum, 1978; Feigenbaum, Buchanan & Lederberg, 1971). Medical areas for which diagnostic expert systems have been developed include internal medicine (Pople, 1977), blood infections (Shortliffe, 1976), glaucoma (Weiss, Kulikowski & Safir, 1977), digitalis therapy (Swartout, 1977), cancer treatment (Shortliffe et al. 1981), and pulmonary function (Feigenbaum, 1979). Two very successful expert systems are PROSPECTOR, which aids geologists in evaluating mineral sites (Duda et al., 1978, Gaschnig, 1979), and R1/XCON which configures VAX computer systems for Digital Equipment Corporation (McDermott, 1980a, 1980b). Both of these systems have demonstrated that expert systems can be developed for practical use in complex domains. In addition to the above systems, there have been several expert systems developed within the field of education, both for teaching/tutoring and diagnosis/assessment; we examine some of these systems herein.

System Components

Figure 1 shows one common representation of an expert system, although no existing expert system contains all of the components shown (Hayes-Roth, Waterman & Lenat, 1983). Ideally, an expert system should contain an appropriate interface including a language processor to carry out communication with the user; a workspace for recording intermediate results; a database of facts concerning the particular case in question; a knowledge base containing problem-solving rules or heuristics; a control structure which handles the problem-solving process; a consistency enforcer which adjusts previous conclusions when new data is acquired; and a justifier that can explain the system's behaviour and conclusions.

The user interacts with the system's interface. Hence, the language processor should be able to parse and interpret the user's questions, answers and commands. It should also be able to supply appropriate explanations to the user regarding its own behaviour. Usually, a restricted form of English is employed.

The knowledge base is the component which contains the system's domain-specific knowledge and problem-solving information. In other words, the knowledge base should contain all the knowledge employed by a human expert. Most expert systems are *production systems*; the *production rules* represent the distillation of human experts' knowledge i.e. an encoding of how the experts handle particular situations. Each rule has a precondition, which must be satisfied before the rule may be applied. All rules are of the form

situation or conditions -------> action.

In addition to the knowledge base, there is a database which contains facts and conclusions concerning the particular case or problem in question. For example, in a medical expert system, the database would correspond to the patient's file. A third component which is employed for representing information is the workspace, sometimes referred to as the 'blackboard'. The workspace is employed to record intermediate results, hypotheses and decisions.

The control structure uses these intermediate findings, as well as the information stored in the database and the knowledge base, to determine what to do next. This component of the expert system is responsible for coordinating the entire problem-solving process. It is often specified as two components, the interpreter and the scheduler. The scheduler determines which of the potential actions should be executed next and the interpreter is reponsible for performing the selected action. In a rule-based system, the scheduler determines which rule will be executed next and the interpreter carries out the execution or task. To perform its job, the scheduler must contain a substantial amount of heuristic information in order to determine which of many acceptable rules is the most appropriate.

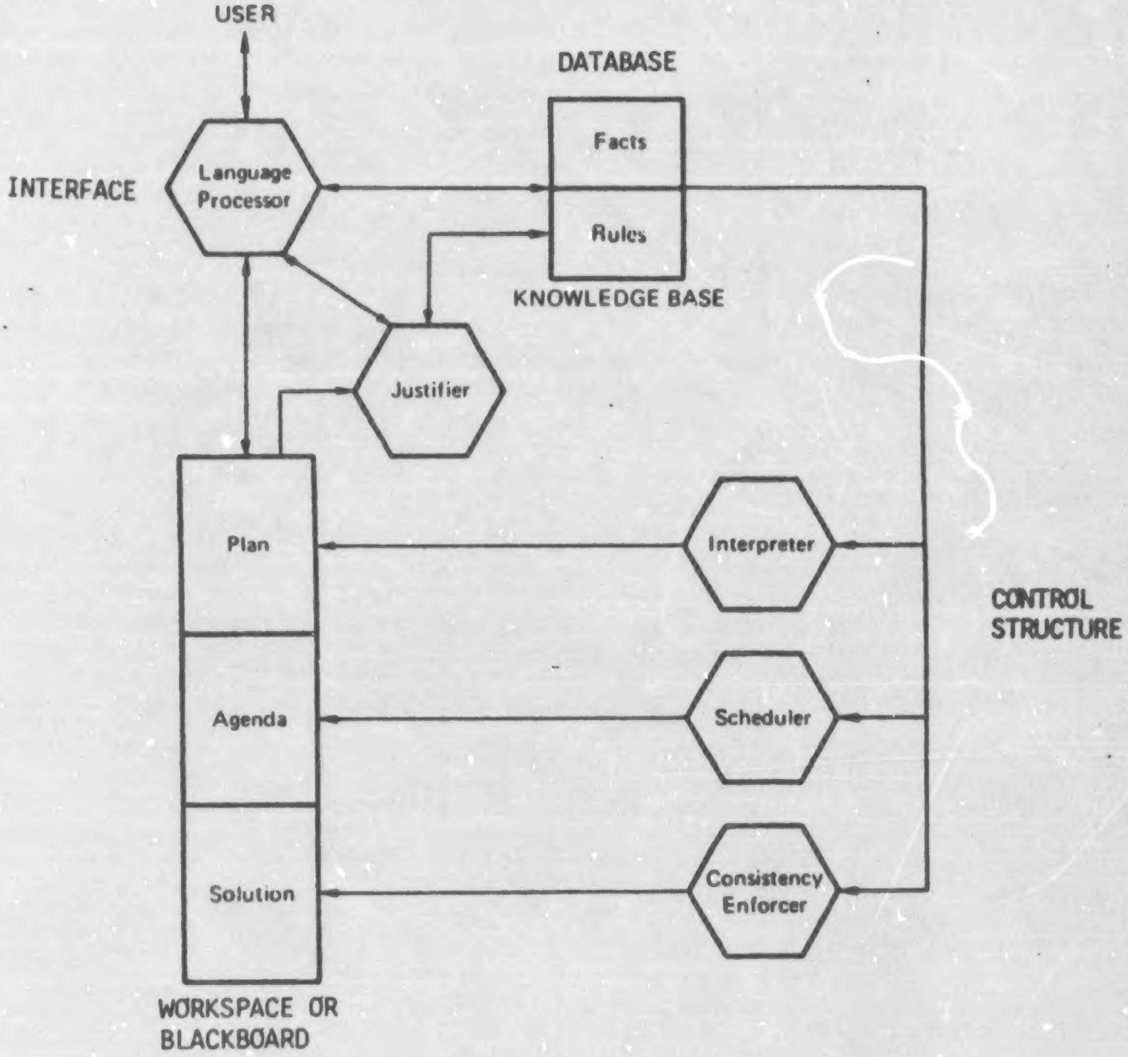

USER
DATABASE
INTERFACE
Language Processor
Facts
Rules
KNOWLEDGE BASE
Justifier
Plan
Interpreter
CONTROL STRUCTURE
Agenda
Scheduler
Solution
Consistency Enforcer
WORKSPACE OR BLACKBOARD

Figure 1: Components of an Expert System (Adapted from Hayes-Roth, Waterman & Lenat, 1983)

The consistency enforcer attempts to maintain a consistent representation of the emerging solution. Most expert systems use some kind of numerical adjustment scheme to determine the degree of belief in each potential decision; this is particularly true of medical expert systems. The idea is to ensure that plausible conclusions are obtained and inconsistent ones are rejected.

The final component, the justifier, explains the actions of the system to the user. The system should be able to explain its actions, including answering questions as to why certain conclusions were reached while others were rejected.

As mentioned earlier, current expert systems do not contain all of these components. Furthermore, there are several possible representation schemes for the experts' knowledge other than production rules. For example, PIP is a frame-based system (Szolovits & Pauker, 1976) and CASNET's knowledge is respresented in terms of semantic networks (Weiss, Kulikowski & Safir, 1977). For further information regarding appropriate knowledge representation schemes, system components, architecture, authoring languages or tools, the interested reader should consult (Hayes-Roth, Waterman & Lenat, 1983).

Expert Systems within Education

Expert Systems for Teaching/Tutoring

The most obvious role for expert systems in education is that of teaching or tutoring. Many recent CAI (Computer-Assisted Instruction) systems can be classified as expert systems because they have an embedded domain expert for the particular subject matter which they are teaching. Such systems are also referred to as ICAI (Intelligent CAI), knowledge-based CAI or AICAI systems, as tools and techniques from AI have been employed in order to make such systems both more flexible and sensitive than traditional CAI programs. Examples of such systems include SCHOLAR (Carbonell, 1970), SOPHIE (Brown, Burton & Bell, 1974; Brown, Burton & de Kleer, 1982), WUMPUS (Goldstein, 1982; Stansfield, Carr & Goldstein, 1976), WHY (Stevens, Collins & Goldin, 1982), EXAMINER (Oleson, 1977), ACE (Sleeman, 1977; Sleeman & Hendley, 1982), QUADRATIC TUTOR (O'Shea, 1979, 1982), EXCHECK (Suppes, 1981). We briefly discuss a few of these systems here. For further information regarding many of these ICAI systems, the reader should consult (Sleeman & Brown, 1982).

One of the first and better-known ICAI systems is SCHOLAR (Carbonell, 1970), which was designed to teach facts about South American geography. Instead of storing geographic information in the form of prewritten frames (which is the approach employed in traditional CAI systems), the program was organized around an associated database which contained simple geographic facts about industries, exports, populations and capitals. SCHOLAR was designed to manipulate its database to generate factual questions, to evaluate the student's answers and to answer questions posed by the student. In other words, SCHOLAR is an early example of a *mixed−initiative* system; both the system and the student can initiate a dialogue by asking questions.

SOPHIE (SOPHisticated Instructional Environment) (Brown, Burton & Bell, 1974; Brown, Burton & de Kleer, 1982) is an ICAI system for electronic troubleshooting. Rather than instructing the user on the subject of electronics, SOPHIE provides the student with a learning environment in which to acquire problem-solving skills by trying out ideas. SOPHIE is a computer-based expert which helps the student develop appropriate hypotheses, test and debug them. The student is presented with a malfunctioning piece of electronic equipment, in which to locate the faults, by taking appropriate measurements. The student can ask questions about the measurements, or which hypotheses should be considered. When the student forms a hypothesis, SOPHIE evaluates it and, if necessary, helps the student debug it.

Many of the early ICAI systems contained little expertise with regard to appropriate teaching methodologies, and the original version of SOPHIE was no exception. Early experiments with SOPHIE I and II indicated a need for additional coaching capabilities. SOPHIE has undergone several extensions, such as the inclusion of a troubleshooting game and a more sophisticated debugger and explainer, and currently contains some tools necessary for student modelling and coaching. However, Brown and Burton have concentrated their efforts regarding student modelling and tutoring/teaching strategies with somewhat simpler task domains (Brown & Burton, 1978, 1982; Burton & Brown, 1982), as we see later.

Another ICAI system which again demonstrated the need for both appropriate student models and teaching strategies is the WHY system which tutors students about physical processes (Stevens, Carr & Goldstein, 1976). The system can carry on a simple dialogue regarding the causes of rainfall. The intent is to teach the student a "causal model" of the mechanisms underlying a wet climate. The original WHY system illustrates a common shortcoming of CAI systems; the system failed to diagnose the underlying misconceptions that are reflected in the students' errors.

Upon examining actual dialogues with tutors, Stevens and colleagues (1976) conclude that much of a tutor's skill as a debugger (e.g. diagnosing conceptual bugs or misconceptions) depends upon knowledge about the types of conceptual bugs that students are likely to have, the manifestations of these bugs, and methods for correcting them. Consequently, an important component of any teaching system is a method for representing, diagnosing, and correcting such misconceptions or bugs.

Other examples of ICAI systems arise in the context of game playing; examples include WEST (Burton & Brown, 1982) and WUSOR (Goldstein, 1982). WEST is a computer-based coach for the mathematical game "How the West was Won". The intent is to provide sufficient guidance but still allow the child to learn by discovery. Simultaneously, one wants to detect the child's misconceptions; this is done through a *differential modeling* technique that compares what the student is doing to what the embedded expert expected. WEST also includes some general tutoring principles to help guide the coaching process.

WUSOR is a computer-based coach for the maze game WUMPUS. As in WEST, WUSOR contains expert knowledge about the game itself. This portion of the system can detect when the student's moves are nonoptimal and which skills are useful to discover the better alternatives. The tutoring component can then discuss the appropriate skills which have not yet been demonstrated by the player.

Expert Systems for Educational Diagnosis

An important aspect of teaching is the ability to anticipate and diagnose a student's misconceptions. This means more than simply noting the child's errors; one must be able to determine the underlying cause of the errors. Some of the systems mentioned above make a concerted effort in this regard and attempt to maintain an accurate and current model of the student's knowledge, skills, errors and misconceptions.

There is, however, another potential role for expert systems which is within the context of educational diagnosis. The computer provides one means of facilitating educational diagnosis within the regular school environment. An expert system could be developed to guide the classroom teacher and/or resource person through the various stages of diagnosing learning disabilities, from the initial screening through to a prescription. At each step, the expert system analyzes the available data and suggests an appropriate next step. It may request information regarding the child's developmental history or academic skills. The administration of a particular standardized test may be advised or it might recommend further assessment of a skill or ability not within its domain of expertise. This might include consultation with a specialist or a referral to an outside agency.

The teacher or diagnostician performs the required task, such as obtaining the requested data, or administering the appropriate test, and supplies this information to the system. After this new data has been assimilated and analyzed the system proposes the next step, and so on. Eventually, the system provides a summary of its diagnostic findings along with a prescription, including appropriate remedial activities and instructional techniques.

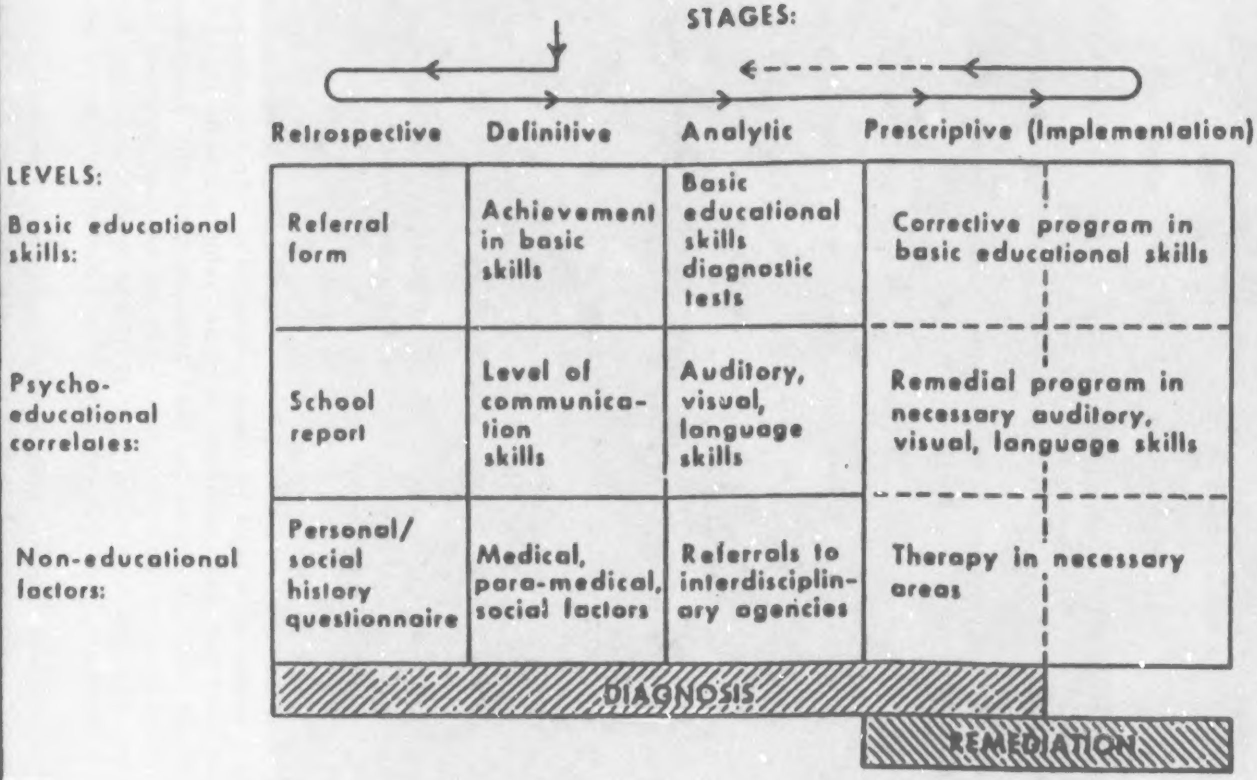
The system does not necessarily test the student directly, nor does it manage the testing activities. Rather it guides the diagnostician. Interaction is between the computer and the diagnostician, with the system posing questions or making appropriate suggestions. Interaction between the computer and the child could also be incorporated. In fact, administration and scoring of some standardized tests has been computerized (Johnson & Williams, 1978; Nichols & Knopf, 1977). Of course, computerized testing need not be restricted to standardized tests.

Whatever the area of assessment, the system must ultimately provide the user with a summary of the diagnostic findings and recommendations for remediation. The latter should include appropriate activities and instructional techniques, as well as suggestions regarding who should participate and where.

As an initial step in the development of an expert system to guide a teacher through the various stages of diagnosing learning disabilities, we have designed and implemented an expert system to assist in the assessment of reading problems (Colbourn, 1982; Colbourn & McLeod, 1983, 1984); the McLeod Educational Diagnostic Model (McLeod, 1982) (see figure 2) is employed as the underlying frame of reference. The present expert system guides the user through the various stages and levels of diagnosis, from the initial suspicion that a reading problem may exist through to the point at which sufficient information has been gathered to plan an appropriate remedial program. Assessment begins with the gathering of relevant data concerning the child's physical, mental, emotional, social and academic developmental history. In addition to the assessment of the child's general skills in academic areas such as reading, spelling and arithmetic, the expert system examines psychoeducational correlates that include those intellectual, visual, auditory and language skill deficiencies which might be related to learning disabilities. As the assessment of the child's learning disabilities progresses, academic skills are subjected to finer and finer scrutiny until the nature of the child's problems has been pinpointed exactly. In addition to determining which skills are missing or inadequate, the expert system must ascertain which skills or abilities have been mastered and which areas represent relative strengths for the child. Such information is necessary for the development of an appropriate remedial program.

The current expert system is implemented as a production system and is programmed in LISP. Information regarding diagnostic procedures is encoded into the system's production rules. The development of the rules is, in itself, a major undertaking. For each component of the model, one must ascertain

- what data are normally collected
- the usual sources of such data e.g. questionnaires, tests, previous assessments



LEVELS:	Retrospective	Definitive	Analytic	Prescriptive (Implementation)
Basic educational skills:	Referral form	Achievement in basic skills	Basic educational skills diagnostic tests	Corrective program in basic educational skills
Psycho-educational correlates:	School report	Level of communication skills	Auditory, visual, language skills	Remedial program in necessary auditory, visual, language skills
Non-educational factors:	Personal/ social history questionnaire	Medical, para-medical, social factors	Referrals to interdisciplinary agencies	Therapy in necessary areas

Figure 2: The McLeod Educational Diagnostic Model (McLeod, 1982)

etc.

- how this information is applied e.g. what facts, suspicions, hypotheses emerge when this new knowledge is assimilated.

The current system's production rules are based upon previous diagnoses undertaken at the Institute of Child Guidance and Development at the University of Saskatchewan.

The system's performance has been evaluated by comparing its diagnostic findings to those of human diagnosticians. In general, the results of the comparison are encouraging. Not only are the system's diagnoses accurate, but because the expert system can perform appropriate analyses (for example, of error patterns) more quickly and more accurately than most diagnosticians, the system's diagnoses tend to be more extensive (within certain limited areas of expertise) than those of human diagnosticians.

Consider the assessment of a child's arithmetic skills. Having determined that this is an area of weakness and perhaps that even subtraction is a problem, one still must determine what aspects of subtraction are proving difficult. Is it poor knowledge of number facts? Is it that the child does not borrow correctly? To ascertain the precise nature of the child's subtraction difficulties, the diagnostician would generally undertake some informal (e.g. non-standardized) testing. Much of this stage of assessment can be computerized as nicely demonstrated by recent research of Brown and Burton (1978, 1982).

BUGGY (Brown & Burton, 1978, 1982) is a program that can determine a student's arithmetic misconceptions or bugs. The system is based on the belief that a student's algorithmic errors are not random but rather are consistent discrete modifications of the correct arithmetic procedure. BUGGY attempts to determine what internalized set of incorrect instructions or rules gives results equal to the student's answer. In other words, given a new problem, BUGGY should be able to predict the student's response.

Included in BUGGY's domain expert is information regarding common arithmetic bugs or procedural errors. In the case of subtraction, 110 primitive bugs are included as well as 20 common compound bugs. The results of all 130 bugs are compared with the student's answers. Based upon these comparisons, the system selects a subset of bugs, each of which explains at least one of the student's wrong answers. The elements of this initial set of bugs are then combined to generate additional hypotheses for the particular student in question. Now the system starts eliminating hypothesized/proposed bugs; for example, one rule employed in this process is to remove bugs which are subsumed by other primitive bugs. This is basically an iterative procedure of removing subsumed bugs and forming combinations of the remaining bugs. Ultimately, each of the remaining proposed bugs is classified according to how well it explains the student's answers. This classification procedure takes into account the number of predicted correct and incorrect answers as well as the number and type of mispredictions. Hopefully at the end of this classification procedure, one bug (primitive or compound) can be selected as the best explanation of the student's erroneous responses.

BUGGY has been successfully employed within the regular classroom and has been used with more than a thousand students. The type of testing and analysis of errors performed by BUGGY is often a time-consuming task for a teacher or diagnostician. It is this type of individual informal testing which is necessary during the latter stages of educational diagnosis in order to determine the exact nature of a student's difficulties. A system such as BUGGY could be incorporated into a more comprehensive system for diagnosing learning disabilities, as described above. In fact, such expert systems could be developed to guide, administer and analyze informal testing for a variety of areas such as phonics, spelling, as well as other aspects of arithmetic. The expert system described in (Colbourn, 1982) is already capable of a substantial amount of analysis concerning a child's phonics skills. The result of incorporating such specialized expert systems into the latter stages of an expert system which guides the diagnostic process would be a powerful tool for facilitating educational diagnosis and assessment within the regular classroom environment.

Conclusions

The abundance of expert systems which have attained a satisfactory level of performance is strong evidence that such systems can be developed for general use within a variety of areas, including education. We have mentioned some ICAI systems which have been developed to teach or tutor various subjects. Although these systems have not been developed with the needs of any special population in mind, their success is again an indication of what can be accomplished.

When developing such a system, one must design

- an expert component which contains the system's domain-specific knowledge e.g. the information which is to be taught
- an appropriate student model e.g. a suitable representation of what the student knows and his/her misconceptions (confirmed or hypothesized)
- a teaching component in which there is embedded sufficient information regarding appropriate teaching strategies as well as heuristic information to control when and how the teaching takes place
- an interface component, capable of conducting a conversation in the student's natural language.

The development of such components is an elaborate task, requiring AI techniques and tools. What one decides to represent within the student model and the teaching component may vary somewhat depending upon the target population. However, the fundamental AI issues (such as appropriate knowledge representation schemes) remain the same regardless of the student population. Hence, the success of the aforementioned ICAI systems is heartening. The same tools and techniques can be employed to develop appropriate ICAI systems for special populations such as children with specific learning disabilities, the mentally handicapped, the visually impaired etc. Also recent success with special keyboards, voice synthesizers, and speech understanding systems such as HEARSAY-II (Erman et al., 1980) are making computers, and hence ICAI systems, more readily available to the physically handicapped.

In addition to systems which teach, expert systems for the diagnosis and assessment of learning disabilities were discussed herein. The development of such systems is clearly feasible, as demonstrated by the existence of prototype systems. Such diagnostic systems could include the informal assessment of a variety of areas such as arithmetic, spelling, phonics etc. In addition to outlining an appropriate remedial program, some of the remedial instruction could be automated if desired.

Clearly, expert systems can be developed for other aspects of special education. In fact, the technology necessary to build an expert system for configuring a VAX computer and for diagnosing reading difficulties is the same; the knowledge encoded into the production rules is the fundamental difference. In other words, the technology exists to build a variety of expert systems to perform any number of tasks within special education. Furthermore, there now exist appropriate authoring tools to assist in the construction of such systems; examples include EMYCIN (Van Melle et al., 1981), OPS (Forgy, 1981), and ROSIE (Fain et al., 1981). For further information regarding authoring tools, see (Hayes-Roth, Waterman & Lenat, 1982). Despite the existence of such tools, the task of developing an expert system is still time-consuming. It generally requires the collaboration of several experts, particularly during the rule-development and evaluation stages. Despite major advances in AI within the past decade, the task of developing an expert system within any complex domain remains challenging.

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ROBOTS AND SPECIAL EDUCATION
THE ROBOT AS EXTENSION OF SELF

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ROBOTS AND SPECIAL EDUCATION:
THE ROBOT AS EXTENSION OF SELF

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ABSTRACT

The robot as an aid to man in his endeavors is an age-old idea, which recently has become more of a reality. While based on mythology and science fiction, the robot as an extension of the human mind and body has become nearly technologically feasible. This paper discusses the use of robots as an aid to the physically handicapped, the requirements for robot performance, and the research agenda necessary for the use of robots in special education in the future.

APPROPRIATE APPLICATIONS

One of the most apt descriptions of a robot for use in education is found in "Strange Playfellow", a short story by Isaac Asimov published in 1940. The robot, named "Robbie" by the child to whom he was assigned, was capable of almost all desirable functions except speech. Robbie was anthropomorpic, capable of perceiving his environment, capable of motion and dexterity, and capable, due to his "positronic brain", of learning and reasoning. Endowed as he was with Asimov's famous "Three Laws of Robotics", Robbie was not only safe for use with humans, but contributed to the safety of humans within his range.

As a playmate, Robbie performed functions that are found to be desirable in robots today. In education, these functions can be put in two categories. First, these functions can be thought of as auxiliary to education. They provide novel interaction with the student, they aid in motivation, in short they act as an extension of the teacher. These functions can be found in many robots and robotic educational systems today, and have been put to productive use in special education. The use of robots as teaching aids ranges from pre-school to university, from attention mechanisms to teaching science and mathematics. The limits to the effective use of these robots are essentially the limits established by the creativity of the teaching professionals using them.

The robot as an extension of self is a very different matter, being controlled by the student to meet the student's personal needs and objectives. The driving functions in the specification of this robot are the student's mode of control and the functionality in successfully fulfilling the student's commands. Meeting the requirements of these functions demands a robot capable of a very high level of sophistication in its logic and its actions--a level that is not present in currently available robots.

The consideration of such a robot raises several questions. First, what characteristics must such a robot possess? In the broadest sense, the robot as extension of self should operate to assist the handicapped student to become as nearly fully functioning in the student's environment as possible, to negate the disability from the handicapping condition. Should such a robot exist, how would it differ from a similar robot in use by non-handicapped students? It would differ very little, perhaps only in adaptive input/output devices required by some conditions. Its use, of course, would be dictated by a more serious need, but its characteristics would make it useful by the general population. The question remains concerning the technological requirements of the robot. The balance of this paper deals with these requirements and practical aspects of achieving them.

THE ROBOTIC EXTENSION

Usefulness by Handicapping Condition

The main handicapping conditions that would be alleviated by the use of robots are those that limit mobility, dexterity, and interaction with environment. The use of the robot in these cases is simply an extension of present philosophies in education. Whether the basis is mainstreaming, cost reduction, or understanding, the result is the assistance of the student to function in an ordinary classroom, as they will be expected to function in an ordinary environment as adults. The robot, then, can be thought of as providing missing or impaired human functions, under direction of the student.

The first major category of conditions consists of orthopedically handicapped, multi-handicapped, and other health impairment. These conditions all, to some extent, limit mobility and dexterity, and thus limit interaction with environment. Remote control devices have been used to some extent, and industrial robots have been used in research environments to perform limited functions such as serving meals. These cases, however, require modification of the environment as well as the use of the robot. Ideally, the robot would perform its functions by interacting with existing environmental controls and by performing services for the student with a minimum of modification of the environment, since this modification cannot be maintained outside the controlled area. By designing a more generalized system for control by the student, the accessible environment is broadened.

The second major category consists of visual impairment and deaf/blind. Obviously, the robot in this case would provide sensory interaction. It would act as a mobile, dextrous adaptive device, allowing the student to perceive the environment and to have the option of directly interacting with it or directing the robot to assist in the physical interaction. For example, selecting and loading a cassette tape in an uncontrolled environment can be a difficult task. With a fully functioning robot, however, the blind student could not only achieve it, but would have several options to exercise, depending on the extent of assistance desired. The deaf/blind student would require more complicated input/output devices to perform physical tasks, but the working of the robot would be the same.

Within these two categories are found the primary common characteristics in the robot extension. These are mobility, dexterity, payload capacity, sensory capability, and intelligence. These characteristics are presently found, singly or in limited combinations, in existing robots. Mobility and dexterity, for example, are found in many educational robots. Intelligence and limited sensory capability are found in many microcomputers and some robot systems. Payload, to the extent necessary to be useful to the handicapped, presently exists only in industrial robots. It is in the combination of these characteristics that the useful fully functioning robot is defined.

Performance Characteristics

What is required in the fully function robotic extension approaches the fictional android, or at least an anthropomorphic device capable of interacting with its environment. While the android helper will remain fictional for some time, the functioning of it can be achieved by a concerted and concentrated effort in developing a robot system based on its requirements, rather than attempting to adapt existing systems. The robotic extension ideal is not a revamped industrial robot, nor is it a modified educational robot, although it shares characteristics with both. What is required is a generalized system, without the inherent design compromises that are made when a robot is designed for a more limited specific purpose.

One of the basic requirements is mobility. Mobility in this case is not simply motion, but motion under internal control to achieve external commands. The motion should be smooth, at speeds ranging from very slow to somewhat in excess of a normal walking pace. Due to its operation in an uncontrolled environment, the mobility system will require a sophisticated control and sensory system in order to adapt.

One of the most severe physical limits on present mobile robots is payload. For effective operation, payload can be defined in terms of books and grocery bags. The typical grocery bag can be loaded with up to 30 pounds of goods, and the robot should be capable of carrying this load as well as gaining control of it and disposing of it. Manipulation of large loads can be expected to occur near the body, while small loads of up to 5 pounds, such as a book, should be manipulated with some dexterity at arm's length.

Dexterity is required to manipulate the environment and objects in it, as well as performing simple maintenance needs of the student. For these purposes at least one arm is required, and it should be capable of at least six degrees of freedom in its motions in order to begin to approximate human arm motions. A grasping device is also necessary. This hand should have at least two independent and continuously controllable fingers with an independent opposable thumb. For fine motions and actions requiring high precision, the hand and arm should be capable of detecting exerted force as well as having a sense of touch. The control of the hand should be assisted by a vision system within the robot and simple binary detectors within the hand itself.

The intelligence of the robot is one of the critical factors in its performance. It must receive and transmit information through its sensory apparatus. It must coordinate basic and arm motion with its command and sensory inputs. It must be programmed at a sufficiently high level to allow the user to command it in a conversational mode. Finally, it must perform these functions with near simultaneity and little perceptible hesitation while continuing to learn and adapt to its environment and its user.

The second critical factor is the combination of power and size necessary to perform the necessary functions. For acceptance and practical use, the robot must be no larger than an average adult. Power systems must be adequate to achieve the motion and payload requirements as well as power the arm and internal senses and computer. This combination will, to a large extent, determine the bulk and stability of the robot.

The robot that meets these requirements is a complex system approaching human capabilities in its functionality. It can move about in its environment, manipulate the environment, and serve the needs of the user. While the robotic extension remains limited in its capabilities, and will not completely replace human assistance in some cases, it meets the basic objective. It vastly improves the ability of the handicapped student to function in an uncontrolled environment and, just as important, it provides a sense of control and independence that is highly rewarding. The robot has grown from an educational aid to a part of daily life.

The State of the Art

While many technological components of the ideal robotic extension exist, we are still a long way from development of an integrated system. The existing systems that come closest to these requirements are the mobile educational robot systems. They have mobility, some dexterity, computer control, and in some cases sensory capability. In their functional capabilities, some existing systems meet all of the objectives, though at a much lower level than what is required.

The limitations of existing systems lie in the extent to which they are capable of continuous operation in the uncontrolled environment. In this respect, all systems are lacking in all functions. This is not to criticize these systems; in fact, they perform to their design criteria in an educational environment. These design criteria assume factors such as supervised use, a smooth hard surface, limited power and dexterity needs, and limited reliance on robot senses.

What is required for development of the robotic extension is a different orientation toward robot design. Existing robots are designed for specific functions or sets of functions. Adapting these for use as general-purpose systems is asking more than their capabilities provide. For the general-purpose robot to become a reality, its design must be done within constraints set by its functional requirements, not within constraints set by capabilities of existing segments of the system. This requires research in system segments within an integrated set of design objectives.

THE RESEARCH AGENDA

Machine Intelligence

Several functions of the robot require extensive capability in machine intelligence. This capability is a combination of artificial intelligence, expert systems, and real-time computing. Artificial intelligence and the development of expert systems combine to provide reasoning ability, learning, and the specialized data and its manipulation necessary to interact effectively with the environment. Real-time capability is necessary for motion, arm, and sensor control.

Sensing capability begins with vision and touch. More specialized senses would include sonar ranging, temperature, and sound. Radio frequencies could be used effectively for communication with external devices such as environmental control or the user's control console. These capabilities presently exist; research needs include packaging, information processing, and the interface and software of the control computer.

An interesting concept that has been used in mobile industrial systems is the environmental map. This is a computer analog of the floor space within the environment. The robot locates itself within this map, and thus knows at all times its proximity to objects in the environment. This map, expanded by the system's ability to learn, would be invaluable in assisting the motion algorithms.

The motion itself requires substantial computing effort, especially considering that motion may be combined with arm motion and sensory interaction. The computer must find a path and then control the robot's motion along the path. If the path is a new one, there will be substantial reliance on external sensors as well as effort in learning the path for later use.

Conversational input and output will put severe demands on the computer. This mode of control is necessary, however, for effective use. There is no reason to expect the user to be a computer programmer. Indeed, there is reason to expect the robot to be controllable by small children who have no knowledge of computer programming. The robot must then respond to natural language commands, and must use natural language when it initiates communication with the user.

All of these factors depend on the computer's decision making capacity, its sheer computing power. The major research effort in this area is in development of computer software for robot control, sensor information processing, conversational input and output, and the artificial intelligence component which makes all internal decisions in response to commands and sensor inputs. With the progress that has been made in large scale integrated circuits and the availability of 32-bit microprocessors, the computer hardware is available.

Physical Characteristics

Dexterity is one of the most critical physical characteristics. It depends on hand design, arm design, and the real-time computing capability. For fine, precise motions a closed-loop system will be required. This closed loop will consist of the arm, hand, computer, and sensors that monitor hand operation. For usable dexterity it is vital that the control loop be closed through the object being handled, not just through the motors driving the hand. Key research areas dealing with dexterity are in the materials in the hand, compact but powerful drive systems, and the coordination achieved through the control computer and the external senses.

Mobility is the second critical physical area. For reliable mobility the robot must have a powerful drive system and be unconstrained by the floor surface. The ability to determine its position is also important; many current models can become "lost" due to slippage on the floor. As with dexterity, mobility requires a compact, powerful power source and close coordination with external senses by the control computer.

Integrated Effort

The heart of the robot system is the coordination of senses and motion. There are many links between the physical aspects of the robot and the control decisions. For this reason, it is vital that the research and development of the robot, while it may take place in many labs and in many specialties, be closely coordinated. Given our present state of technology, all of the functions of the robotic extension are feasible. It is their packaging into a single working unit that is the challenge. As design compromises are made, and they will be, the coordinated effort must insure that changes in one area do not detract from others, and that design efforts continue to be focused on the overall objective--a fully functional robot that is an extension of the user's mind and body.

Practical Considerations

While many things are possible, they have price tags, and it would be foolish to embark on the development of a new robot without considering the price. Related to the price is the level of penetration into the user population. Let us consider two extreme cases of the use of robots. First, assume that every student under PL 94-142 is to be given a robot, and that this policy is continued as new students enter the populations. Based on the size of the 1981-82 population of orthopedically handicapped, multihandicapped, blind, deaf/blind, and other health impaired, and a cost of $10,000 per robot, the initial cost would be $2.5 billion dollars, with succeeding annual costs of $125 million, in addition to research and development costs. At the other extreme, assume that the robots are to be assigned only to teachers specializing in these categories. This cost would be approximately $20 million plus research and development costs.

This raises some philosophical questions regarding the proper strategy. In the first case, this is a very large expenditure on a very small segment of the total population. Yet it has many advantages in the productive functioning of the handicapped in society. The second case has a much smaller cost, but a much more limited usefulness. There is a philosophical problem with the second case as well. The students could use the robots on a limited basis in school, but would be required to purchase their own. If this were not possible, we would be putting the students into an artificial environment, and training them to cope with it, followed by expecting them to function without a vital part of the environment upon which they would come to rely. It seems almost immoral to teach reliance on a system and then make it practically unavailable.

Given that the first case is technologically possible, it is also desirable. Before it can be started, however, research is needed in the economic viability of the program. Cost/benefit analyses need to be done, especially considering the potentially high cost of not embarking on the robot research and development program. Considering the size of the investment, it may be necessary to involve both public and private sector funding sources, especially since the result will be a salable product.

CONCLUSION

There is no question as to whether this research will be done. The questions are when will it take place and how will it be accomplished. Certainly its economic aspects will have much to do with when and how it is done, and this could be used to advantage in bringing this robot into development much earlier than might be thought. Considered only as an aid to the handicapped, this project could be thought too expensive. It is very important to recall, however, that this robot and its counterpart for general use will differ only in adaptive input and output devices, if at all. This puts a very different light on its economic viability, and provides a unique opportunity to the field of special education. Many existing educational systems in special education are either highly specialized for their user populations or are adaptations of systems developed for the general population. This robot systems presents an opportunity for special education to take a leadership role in its development, and then make it available to the rest of the world years sooner than it would otherwise come to be.

BIOGRAPHICAL DATA

Dr. D. L. Kimbler is an associate professor of industrial and management systems engineering at the University of South Florida, where he is also Director of Automation, Robotics, and Productivity in the Center for Engineering Development and Research, and serves on the steering committee for the Center For Excellence in Mathematics, Science, Computers, and Technology. He is a Senior Member of the Institute of Industrial Engineers and is presently Director-Elect of the Institute's Manufacturing Systems Division. Dr. Kimbler is also a member of the Computer and Automated Systems Association and the Robotics Institute of the Society of Manufacturing Engineers and of the American Society for Engineering Education. His major interest in robotics in in systems integration and applications, and he works in these areas as an engineering consultant. He is a registered professional engineer in Florida.